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The effect of initial deflection on the stress distribution in a panel of plating of a ship under tensile load

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Massachusetts Institute of Technology

THE EFFECT OF INITIAL DEFLECTION ON THE STRESS DISTRIBUTION IN A PANEL OF PLATING OF A SHIP UNDER TENSILE LOAD

Wilfrido T. Freire Duenas
and
German Winkelmann De La Cruz

THE EFFECT OF INITIAL DEFLECTION

ON THE STRESS DISTRIBUTION IN A PANEL

OF PLATING OF A SHIP UNDER TENSILE LOAD

Letter on front cover:

THE EFFECT OF INITIAL DEFLECTION

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PANEL OF PLATING OF A SHIP UNDER

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and
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ABSTRACT

THE EFFECT OF INITIAL DEFLECTION ON THE STRESS DISTRIBUTION IN A PANEL OF PLATING OF A SHIP UNDER TENSILE LOAD

by

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Submitted to the Department of Naval Architecture and Marine Engineering on May 24, 1954, in partial fulfillment of the requirements for the degree of Naval Engineer

OBJECT

The object of this investigation was to obtain quantitative data of the stress distribution in a panel of plating representing the plating of a vessel under tensile load, in order to establish a relation between the ratio of maximum stress to average stress and the ratio of initial deflection to plate thickness.

It is expected that a complete investigation of the effect of initial deflection on the stress distribution in a panel of plating will provide a technical criteria to specify the maximum allowable initial deflection to avoid excessive stress in the material.

METHOD

Four specimens were made of 1/8" plate with welded stiffeners forming 3 panels of 18" x 6". The models were designed to be bolted to pulling members adapted to fit a 300,000 pound tensile testing machine. Roughly the initial deflection of the center panel of the models were: zero, 1/8", 3/16" and 1/4".

The samples were tested using the stress-coat technique to determine the direction of the principal stresses.

SR-4 strain gages type A-3 were installed in two rows, one at the center of the panel and the other near the transverse stiffener, at both sides of the plate.

The samples were tested by applying the load gradually, and the strains recorded at each interval of load.

Plots were made of the load versus strain for each strain

gage. From these diagrams strains were obtained at loads of 20, 40, 60, 80 and 100 kips, and these values were plotted against the position of the strain gage on the plate. The mid-depth strain distribution was obtained by averaging the strains at each point on both sides of the plate.

From the strain distribution diagrams the maximum and minimum strain values were obtained, as well as the average strain in the plate, at each level of load. The ratio of maximum and minimum strain to average strain in the plate were thus obtained, and these values plotted against the ratio of initial deflection to plate thickness.

The strain distributions at 60 kips load were used to check the data, by comparing the integration of stress times cross sectional area with the corresponding load.

RESULTS AND CONCLUSIONS

It was observed that when deflection exists the strain is not uniformly distributed. The maximum strains were found on the unstiffened face of the panel at about the quarter points. The minimum strains were found on the stiffened face, which is the convex face of the panel, at about the center of the panel. The mid-depth maximum strains were found close to the stiffeners.

The ratio maximum to average strain increases almost linearly, within the elastic region of the material, with the increase of the ratio initial deflection to plate thickness; the reverse is the case of the ratio minimum to average strain. All of these ratios approach to unity with the increase of load.

It should be noted that the maximum stresses were observed on the concave face, and that on the convex face the stress was so small that it became negative, or compressive stress, for initial deflection thickness ratio greater than one.

RECOMMENDATIONS

1. Construction and testing of samples of different aspect ratio.

2. Construction and testing of samples with low depth of stiffeners welded at both sides of the plate, in order to obtain the neutral axis of the stiffeners in line with the neutral axis of the plate to eliminate bending moment effects.

Thesis Supervisor: JOHN HARVEY EVANS
Associate Professor of Naval Architecture

Cambridge, Massachusetts

May 24, 1954

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the requirements for the degree of Naval Engineer, we submit herewith a thesis entitled, "The Effect of Initial Deflection on the Stress Distribution in a Panel of Plating of a Ship Under Tensile Load".

Respectfully yours,

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I. INTRODUCTION

In the structural design of a vessel the hull is considered to work as a beam. The difference between the buoyancy distribution and the weight distribution causes a longitudinal bending moment.

It is standard practice to design the strength of the hull, by considering the vessel in two extreme conditions: floating on a wave with the same length of the vessel and with the crest at each end of the vessel, called "sagging condition", and with the crest admiship, called hogging condition. These two conditions are considered to be the most severe manners of loading.

Tests have been made for many years to prove that the hull works as a beam. The first extensive experiments were carried out on the 200 feet transversely framed British destroyer "Wolf" in 1903, and while in many respects setting the pattern for subsequent work, they left many questions unanswered principally because of the scanty strain data taken below the vessel's neutral axis. In 1930 two identical 310 feet transversely framed U.S. destroyers, the "Preston" and the "Bruce", were observed while being loaded in sagging and hogging respectively. Within the past three years another British destroyer, the 355 feet longitudinally framed "Albuera" was similarly loaded in hogging. All these vessles were of riveted construction and were loaded by means of being supported on piers in drydock as the water level and the internal weight distribution was varied. The "Preston", "Bruce", and "Albuera" were loaded to destruction when complete buckling of deck or bottom structure occurred. Except on the "Wolf", for which fore and aft strains only

were measured, multi-axial plain strains were determined enabling principal stresses in magnitude and direction to be calculed. In all cases, stress distribution was found to be in generally good agreement with the classical beam theory, even for extended ranges of loading.

During the past World War II, the emergency merchant fleet was built almost entirely by welding type of construction. Some of these ships were reported damaged by cracking of the hull structure. Investigations of these failures arrived to the following causes of failure:

(a) Stress concentration due to notch effect, being the notch introduced by poor design (corner of hatches, non-continuity of longitudinal members), or caused by poor welding (low penetration, inclusions, blows in the melted metal).

(b) Brittle fracture at low temperature.

These causes explained the failure of vessels that cracked due to notch effects, or that failed because the material had a high critical temperature, but failed to explain why well designed vessels and well constructed suffer cracks in summer when a sister ship is still in service.

A theory advanced to the authors by Professor J. H. Evans, of the Massachusetts Institute of Technology relates the variation in stress to the amount of initial bulge in the panel between stiffeners. If an initial bulge exists in a section of ship plating of a transversely framed vessel, and this section is loaded in tension, the part of the plating containing the bulge will be unable to assume its apportioned share of the load until the deflection is removed; the

section of the plating adjacent to the longitudinal stiffeners will therefore receive and maintain a disaproportionately high part of the load. It is conceivable that the high stresses developed could cause surface crackings, and subsequent failure.

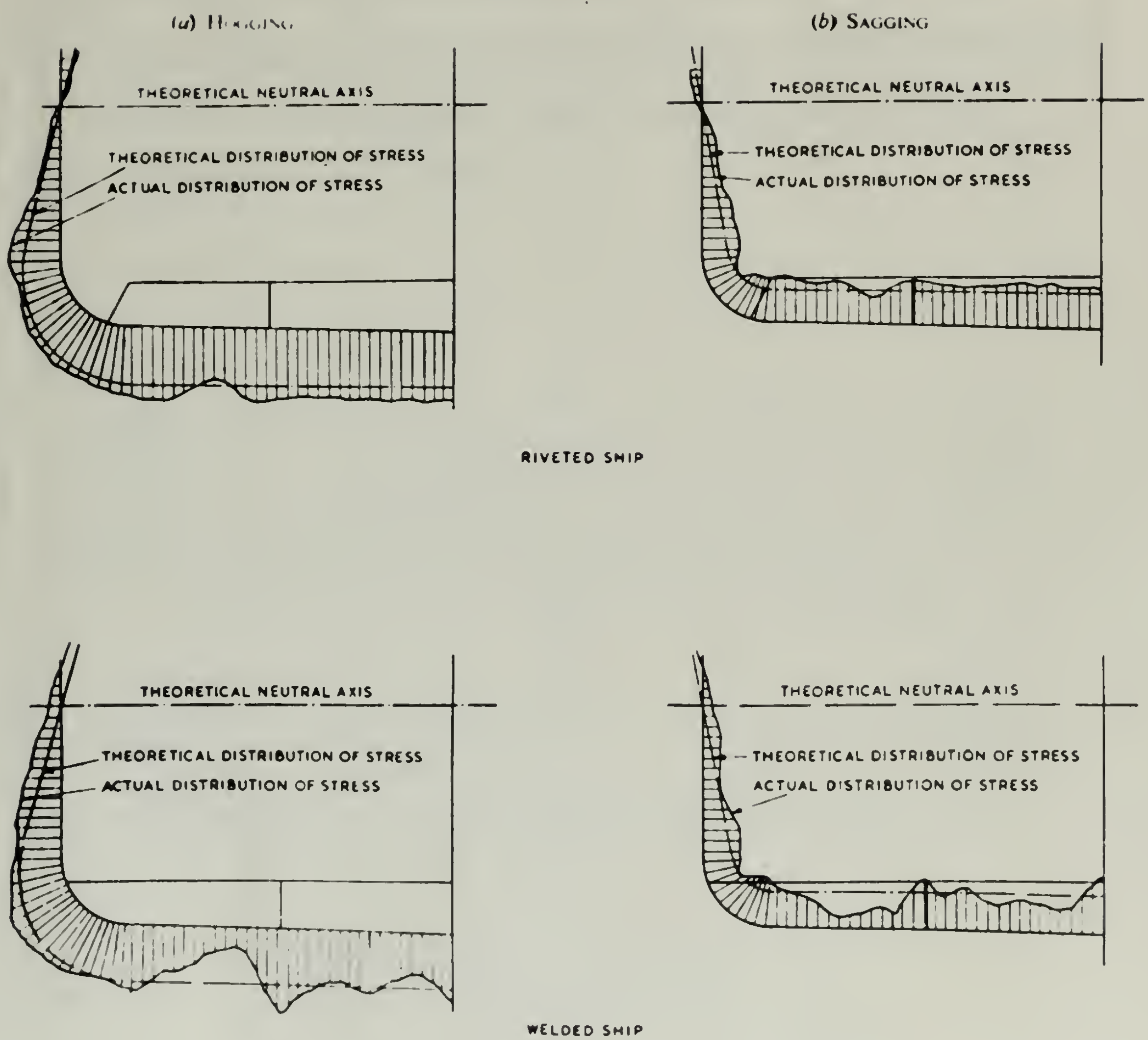
Several investigations have included observations which tend to substantiate the foregoing idea. The Admiralty Ship Welding Committee reported full scale tests on the British identical cargo ships "Ocean Vulcan" and "Clan Alpine", and on identical tankers "Neveritas" and "Newcombia"; one vessel in each pair was all riveted while the other was predominantly all welded. The findings of interest to this report are well summarized in Figure I. The stresses in way of the longitudinal stiffeners of the welded ships, for both hogging and sagging conditions, are much greater than the stresses clear of the stiffeners. This is not true for the case of riveted ships, and the difference could be laid to the minor accommodations in the riveted joints to suit the imposed loads.

What the allowable limit of unloaded plating unfairness should be is a question which needs answering for the benefit of all and the limit which insures against crack formation at the panel supports under the maximum coplanar loading anticipated is the ultimate criterion to be used in coming to a decision.

However, it seems that an excessive unloaded deflection may be attained not only during construction, but by growth under the lateral water pressure or the ship hogging and sagging loadings. For such increasing permanent set to take place under ship service conditions apparently some initial unloaded panel unfairness is also necessary.

FIGURE I

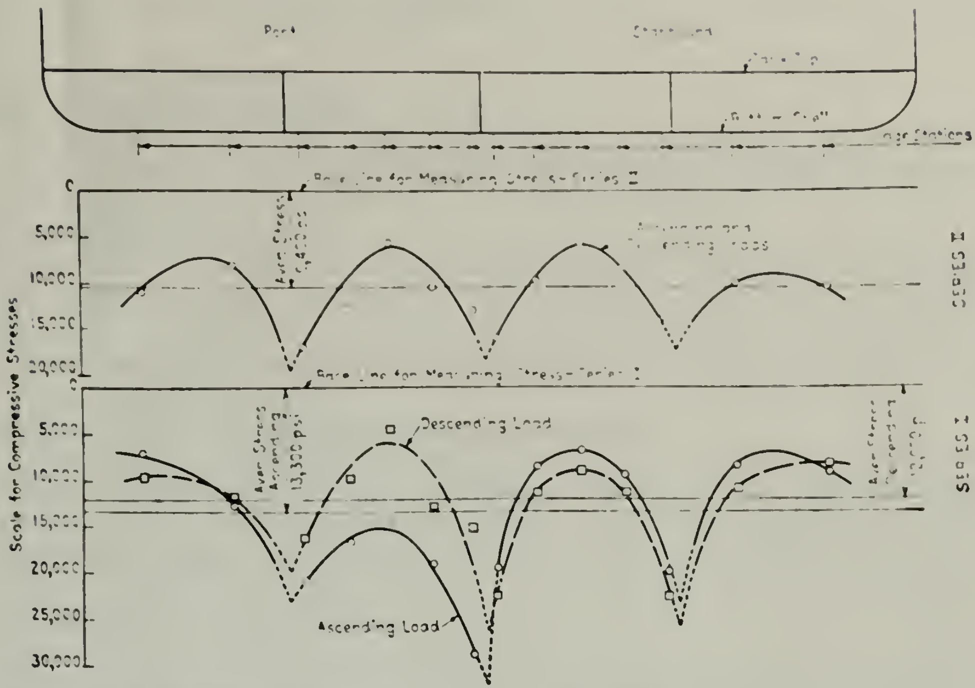
Distribution of longitudinal stresses for bottom shell plating near amidships for merchant vessels.



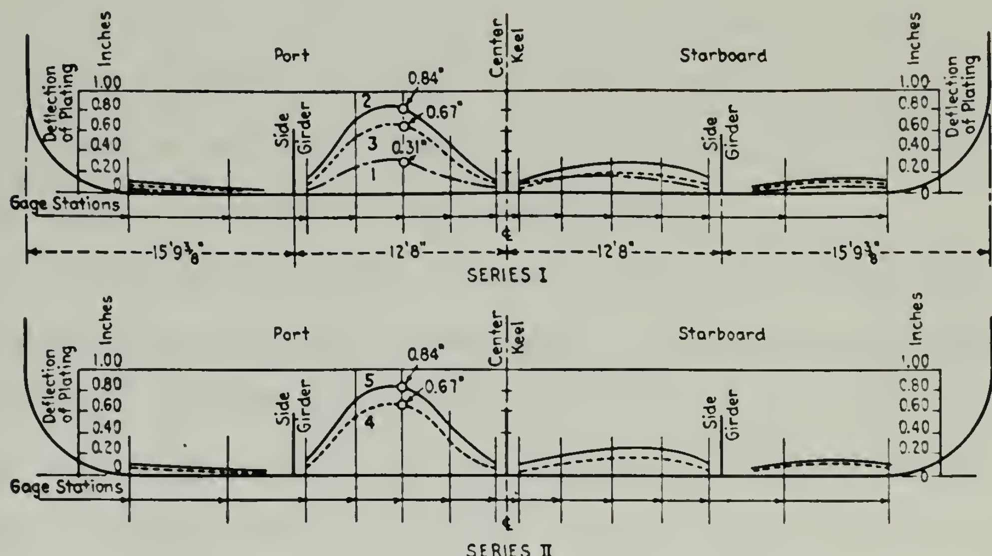
but its limiting value is presumably less than that which makes for sufficient peaking of stress in the fore and aft direction at the boundaries to cause the crack which may immediately or subsequently propagate under the proper conditions, probably including low temperature, or perhaps some transverse strain restrain offered by the framing. Figure II illustrate the case of increasing unfairness of the plating caused by the longitudinal bending moment, from observations made on experiment carried out on the "Philip Schuyler".

Unfairness under alterante tensile and compressive stress naturally compounds the evils.

FIGURE II



Longitudinal Membrane Stresses for Hog Moment of 134,000 Foot-Tons



1 Initial position of bottom plating
2 Position under first hogging moment of 134,000 ft. tons (hog 1)
3 Position on return to 20,000 ft. tons (inter-hog 2)
4 Position under 20,000 ft. tons (inter-hog A & inter-hog B)
5 Position under second hogging moment of 134,000 ft. tons (hog A)

Deflection Profile of Bottom Plating
Midway Between Two Frames Amidships

Bottom Plating Behavior on the PHILIP SCHUYLER

II PROCEDURE

2.1 Design of the Test Section

The design of the test section was governed by the following practical considerations:

a) The load capacity and size of the available testing machines.

b) Cross sectional area of the test section to obtain proper stress values with the selected testing machine.

c) Linear dimensions of the specimen to fulfill the selected cross sectional area, considering the proportion of dimensions used in ship building practice.

d) Desirability of uniform stress distribution along the loading edges of the section to be tested.

With this considerations in mind the following was done. A testing machine of 300,000 pounds of rated load capacity was selected, which has a maximum destructive load of 225,000 pounds, one of the largest available machines in order to reduce scale effects.

In the transverse framing system used in naval architecture, the common aspect ratio is from 3 to 3.75; these values were obtained from the Rules of the American Bureau of Shipping. The aspect ratio 3 was selected, and a panel of 6" x 18", with a plate of 1/8" thickness was considered adequate. Stiffeners of 1/4" thickness plate, and of 2 1/2" depth were used, avoiding the use of profiles like "L" or "T" to facilitate the installation of the strain gages.

With the above dimensions we obtain a cross sectional area of the test section of 4.25 square inches, thus, the average stress with the

destructive loading capacity of the testing machine was 53,000 psi; this was considered satisfactory.

The test section with its dimensions is shown in figure III. It can be noted that three panels were used; the panel to be deflected was the central one, where the strain measurements were made, the other two panels being provided to obtain a more uniform stress distribution, and they were not deflected.

The neutral axis of the complete test section without initial deflection was calculated to be 0.449 inches from the unstiffened face of the plate. Considering that in way of the stiffeners the neutral axis shifts toward the mid-depth of the stiffeners, and that at the midway between stiffeners the neutral axis shifts toward the mid-thickness of the plate, there was a compromise to fulfill for the application of the load. The test sections were designed to be loaded in a plane through the mid-depth of the plate, and the scantlings of the stiffeners were decreased at the ends, as shown in figure III.

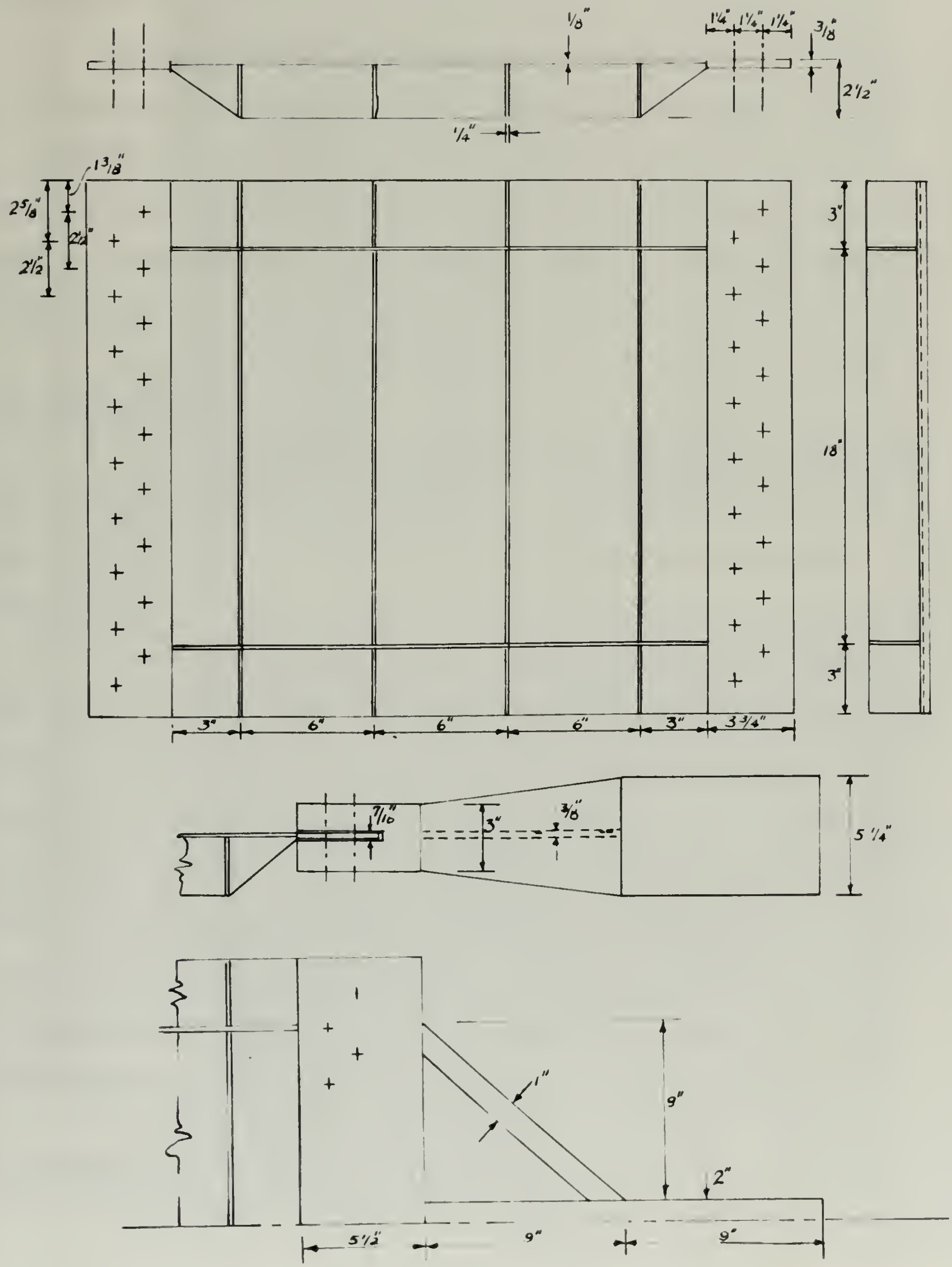
2.2 Design of the Pulling Members

The pulling members were designed to work under the yield point of the material at the maximum load capacity of the machine in order to minimize the deflection of the members and to obtain a fairly uniform stress distribution on the test section.

The linear dimensions obtained from the design calculations are shown in figure III. It may be estimated that the weight of each pulling member was about 250 pounds, and their cost much higher than that of the test section; therefore, it was considered desirable to have detachable

FIGURE III

TEST SECTION AND PULLING MEMBER



pulling members instead of having them welded to the test sections, in order to facilitate the handling of the equipment and to reduce the initial cost.

The test section was attached to the pulling members by means of 16 bolts of 1/2" diameter, and the strength of this joint considered as a riveted joint was greater than the strength of the test section; it should be noted that the thickness of the plate is increased at the bolted joint in order to obtain greater strength at the joint than at the test section.

2.3 Fabrication

The test sections and pulling members were made at "Saul Avery Steel Company", Cambridge, Massachusetts. The material used was commercial mild steel. The process of fabrication was arc welding. A heat treatment for stress relief was used at the end of the fabrication.

The test sections with zero nominal deflection and with 1/8" nominal deflection received the initial deflection in the central panel during the fabrication by effect of the welding of the stiffeners. The test section with 3/16" nominal deflection was hammered to increase the bulge caused by welding to the desired amount of deformation. The test section with 1/4" nominal deflection received the deflection of the central panel by lateral pressure using a compression testing machine of the Laboratory of Testing Materials at the Massachusetts Institute of Technology, with the aid of a piece of wood to avoid identations.

2.4 Measurement of the Initial Deflections

The initial deflection was measured with a dial gage graduated in

thousandths of an inch, mounted in a metal frame as shown in Figure IV. The frame was mounted in such a way that zero readings were obtained at 3 corners of the panel.

Measurements were made at intervals of 1/2 inch along parallel lines spaced 1/2 inch apart. Observed deflections are recorded in Table I in Appendix A.

The initial deflection data was plotted on cross-section paper, and contours of constant deflection were drawn, as shown in the "Contour Map of Initial Deflection", Figures V, VI, VII, and VIII.

To obtain the initial deflection of each test section, the following procedure was used:

a) The arithmetical mean averages of readings taken along the long borders of the panel, within the central 10 inches, were first computed.

b) Next, the arithmetical mean average of readings taken along the transverse centerline of the panel were computed, within the central 10 inches, which is the section that showed the maximum deflection.

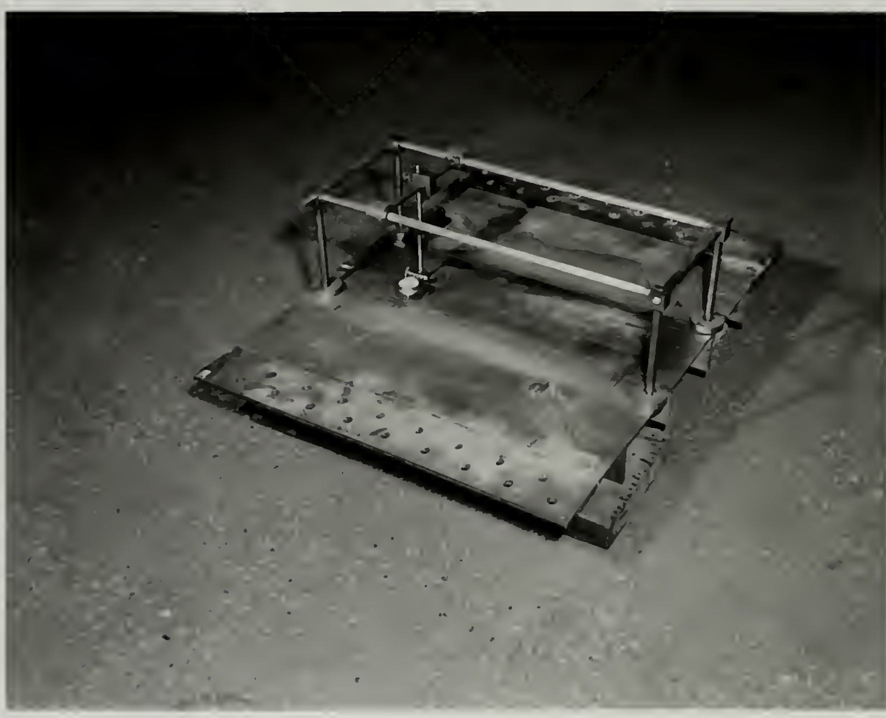
c) Finally, the difference between half the sum of the border arithmetical mean values and the center line arithmetical mean value gave the resultant average deflection of the panel. This calculation is shown on Table V in the Appendix C.

2.5 Stress-Coat Tests

The surfaces of the center panel of each test section were cleaned and polished with emery cloth. Next the surfaces were sprayed with precoat

FIGURE IV

Specimen



Measurement Device of Initial Deflection

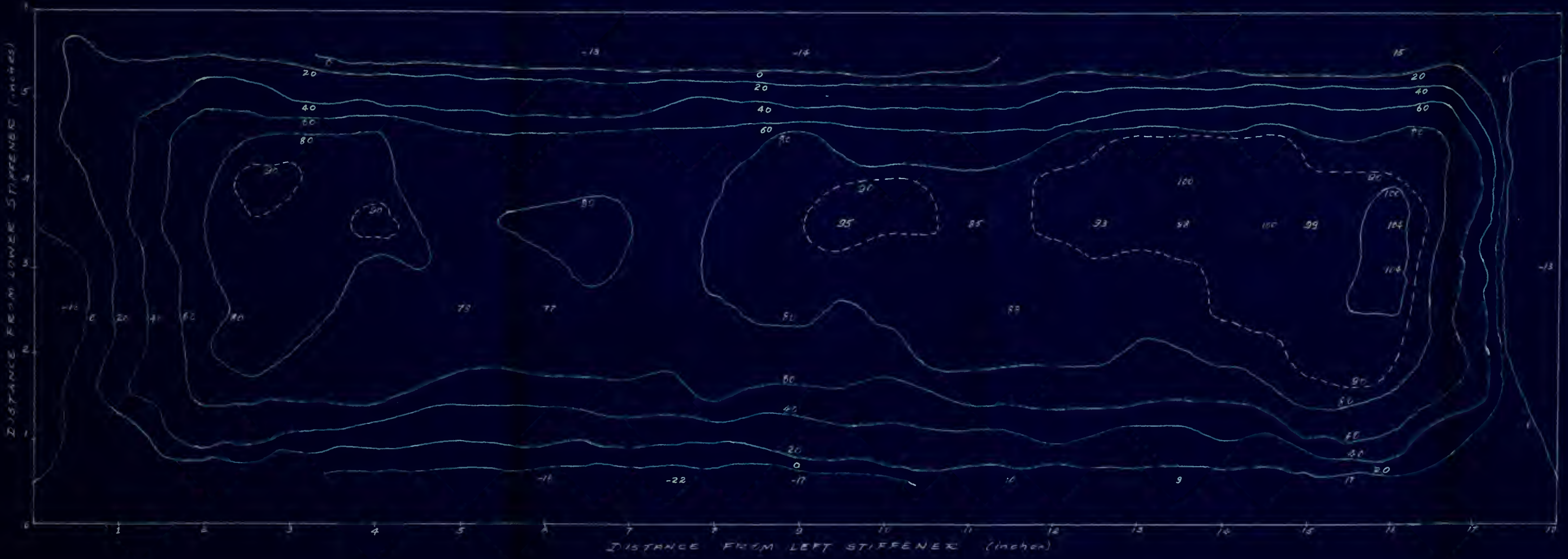
CONTOUR MAP OF INITIAL DEFLECTIONS

NOMINAL DEFLECTION ZERO

PANEL CONCAVE ON UNSTIFFENED SIDE
MEASUREMENTS IN THOUSANDS OF AN INCH

CONTOUR MAP OF INITIAL DEFLECTIONS

NOMINAL DEFLECTION 1/8 INCH
PANEL CONCAVE ON UNSTIFFENED SIDE
MEASUREMENTS IN THOUSANDS OF AN INCH



CONTOUR MAP OF INITIAL DEFLECTIONS

NOMINAL DEFLECTION 3/16 INCH

PANEL CONCAVE ON UNSTIFFENED SIDE

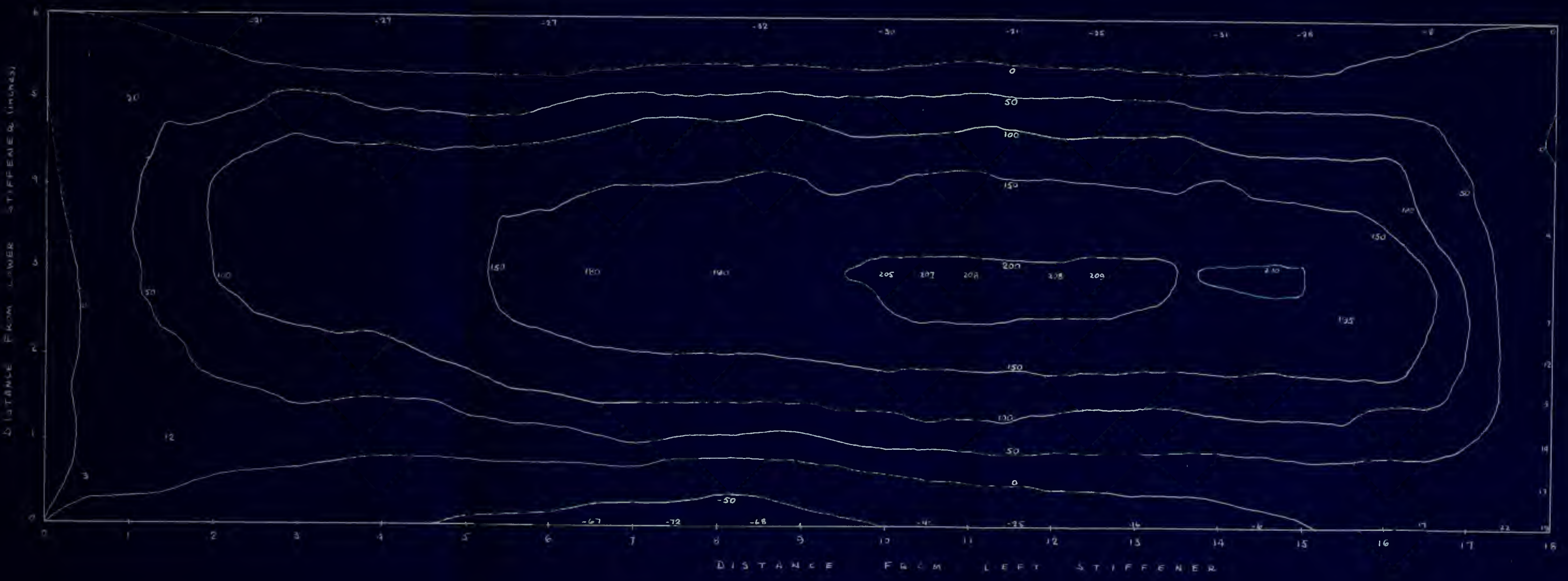
MEASUREMENTS IN THOUSANDS OF AN INCH

CONTOUR MAP OF INITIAL DEFLECTIONS

NOMINAL DEFLECTION 1/4 INCH

PANEL CONCAVE ON UNSTIFFENED SIDE.

MEASUREMENTS IN THOUSANDS OF AN INCH.



in order to obtain a smooth surface. Then the stress-coat was applied. The precoat and the Strain Indicating Coating ST-1208 were manufactured by "Magnaflux Corporation", Chicago 31, Illinois.

The type of stress-coat selected was determined by the weather conditions, since temperature and humidity changes may cause cracking of the stress coat. The drying period of the stress-coat was 24 hours. In every test the weather condition did not change from the time of application of the stress coat to the time at which the test was performed.

The specimens were loaded to 80,000 pounds in order to obtain a complete crack pattern of the stress-coat. The crack pattern appeared only on the unstiffened side of the panel: no cracks were observed on the other side.

An attempt to make the crack pattern stand out by using dye-etching failed because the stress-coat was dissolved by the dye and the pattern disappeared.

In order to obtain a record of the crack pattern, it was necessary to mark the cracks with ink or pencil on the stress-coat itself. The next step was to transfer the delineated pattern to transparent paper. The "Pattern of Cracks in Stress Coat", are shown in Figures IX, X, XI, and XII.

The strain gages were aligned with the direction of the principal stresses, which is perpendicular to the direction of the cracks. It was considered that the strain gages on the stiffened side of the plate, where no crack pattern was formed, should be oriented in the same direction as the strain gages on the unstiffened side of the plate, because the direction

PATTERN OF CRACKS IN STRESS-COAT

ZERO(in) NOMINAL DEFLECTION PANEL

Pattern of Cracks in Stress-Coat

1/8 in Nominal Deflection Panel

PATTERN OF CRACKS IN STRESS-COAT

3/16 in. NOMINAL DEFLECTION PANEL

PATTERN OF CRACKS IN STRESS-COAT

1/4 IN. NOMINAL DEFLECTION PANEL

of the principal stresses would not change through the small thickness of the plate.

It should be noted that the cracks of the stress-coat were not produced at low level of load, but that they started to appear for loads above 60,000 pounds. Therefore, the orientation of the strain gages was governed by the direction of the principal stresses at high loads. It it believed that the direction of the principal stresses changed with the load. Because the magnitude of the deflection probably changed with the load; therefore, the measured strains at loads other than that which caused the cracks are not the true values of the principal strains.

Nevertheless, the strains measured by the strain gages located in the transverse centerline of the panel are undoubtly principal strains; since by symmetry, the principal strains should be oriented in the direction of the applied load, and the fact that the observed cracks are perpendicular to the transverse centerline on all specimens supports this conclusion. This consideration is emphasized to validate the conclusions of the experiment.

2.6 Application of Strain Gages

SR-4 Strain Gages type A-3 manufactured by "The Baldwin Lima-Hamilton Corporation", Philadelphia 42, Pennsylvania, were used. They were applied using SR-4 Pre-Coat and Cement, following the manufacturer's instructions using 64 Strain Gages per test section.

The locations considered ideal for the strain gages to obtain the curve of strain distribution is shown in Figures IX and through XII, but due to some small irregularities in the surface of the plate some of the

strain gages where applied in a slightly different location as indicated by Table II in the Appendix A. "Front Face" indicates the unstiffened side of the plate, and "Back Face" the stiffened one.

After the strain gages were applied and the cement had dried for 24 hours, the gages were electrically tested for continuity and insulation from the plate; the minimum insulation measured was 25 megohms, which is far above the required insulation of 5 megohms. Figure XIII is an illustration of a test specimen with the strain gages in place.

2.7 Strain Measurement

The testing machine used to load the specimens in tension was a "Southwark-Emery" hydraulic type, MIT serial 105. The control panel of this machine and the set-up of the equipment is shown in Figure XIV.

The strain gages were connected between ground and a switch-board formed by knife switches. Through the switch-board, the strain gages were connected to an SR-4 Strain Indicator, type L, serial H80797, manufactured by Baldwin-Southwark.

An initial load of 20,000 pounds was used to line-up the specimen in the testing machine, and then the load was reduced to zero to obtain the strain reading at zero load. Next the load was applied gradually, and the strains recorded at each level of load, as indicated in Table III in the Appendix A.

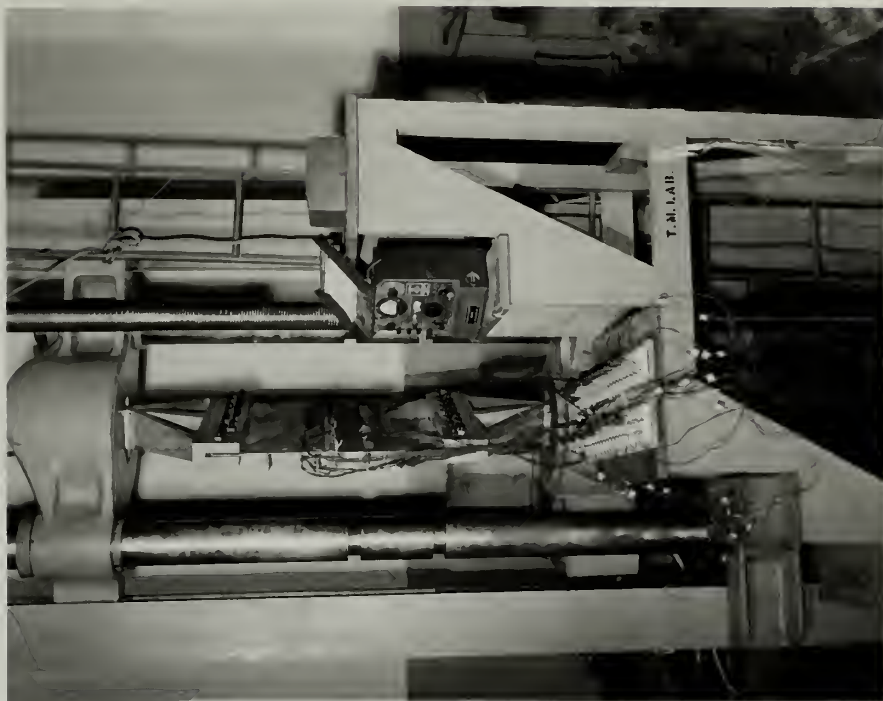
It should be noted that during the application of the load to measure the strains, some slip of the pulling members at the jaws of the testing machine was noticed, and this fact somewhat invalidated the

FIGURE XIII

Specimen with Strain Gages

FIGURE XIV

Hydraulic Testing Machine
Control Panel



Set-up of the Equipment

strain reading at zero load, because of a probable change in the line-up of the specimen. This effect was particularly noticeable when the plate with 3/16" nominal deflection was tested.

2.8 Strain-Load Curves

The recorded strains were plotted against the applied load to check the correctness of the readings, as shown in Figures XV through XLIII. These curves represent the graphical average relation of strain to load at each strain gage position.

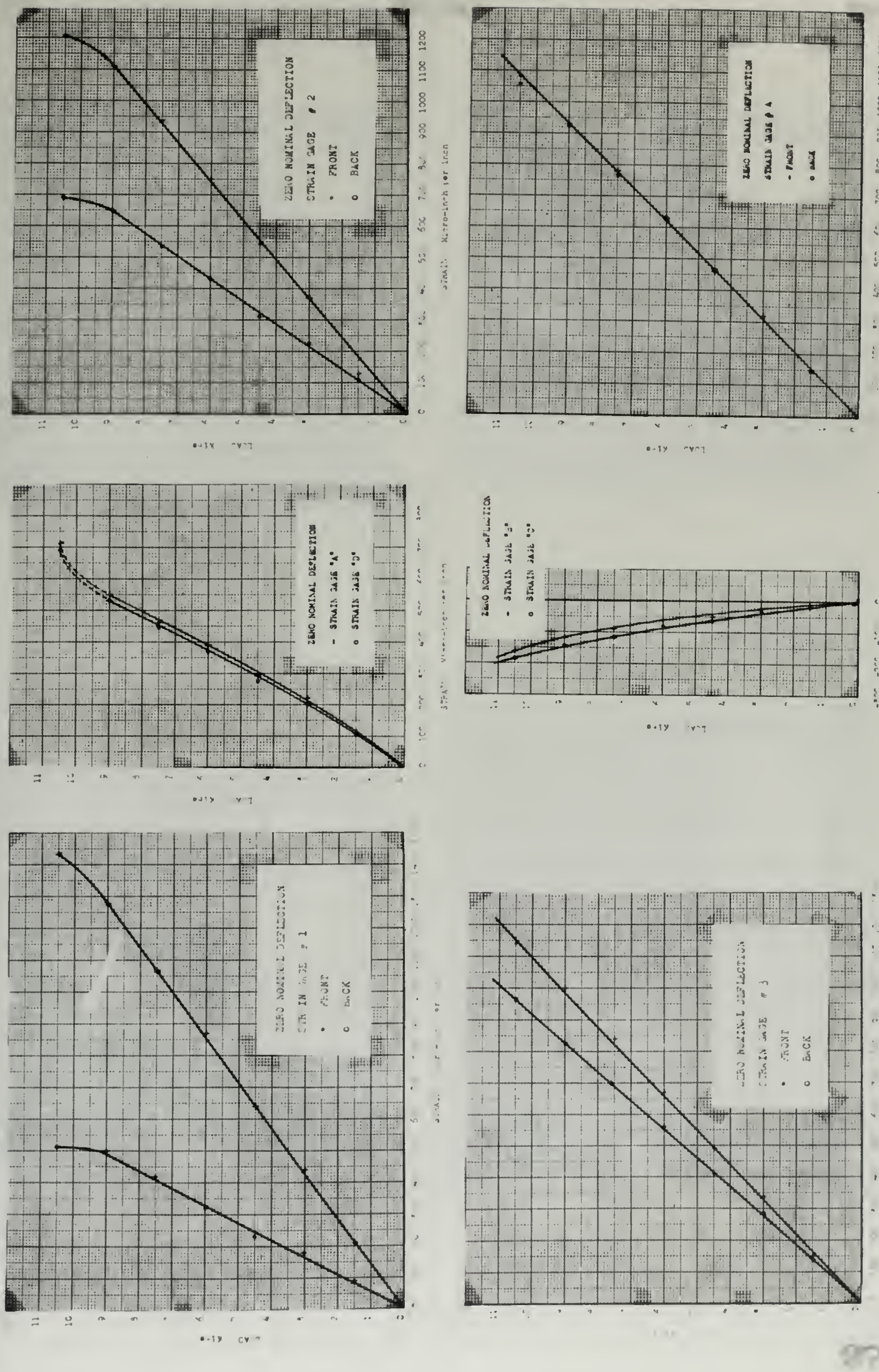
2.9 Strain Distribution Curves

From the Strain-Load curves, the strain at each strain gage was obtained for five levels of load, as recorded in Table IV in Appendix B. These strains were plotted against the positions of the strain gages to obtain the strain distribution curves at different levels of load for both the front face and the back face of the plate. The arithmetical mean average between both faces gave the strain values at the mid-depth of the panel. These values were also plotted against the position of the strain gages to obtain the strain distribution at the mid-depth of the plate. The strain distribution curves are shown in Figures XLIV through LVI.

2.10 Strain-Deflection Relationship

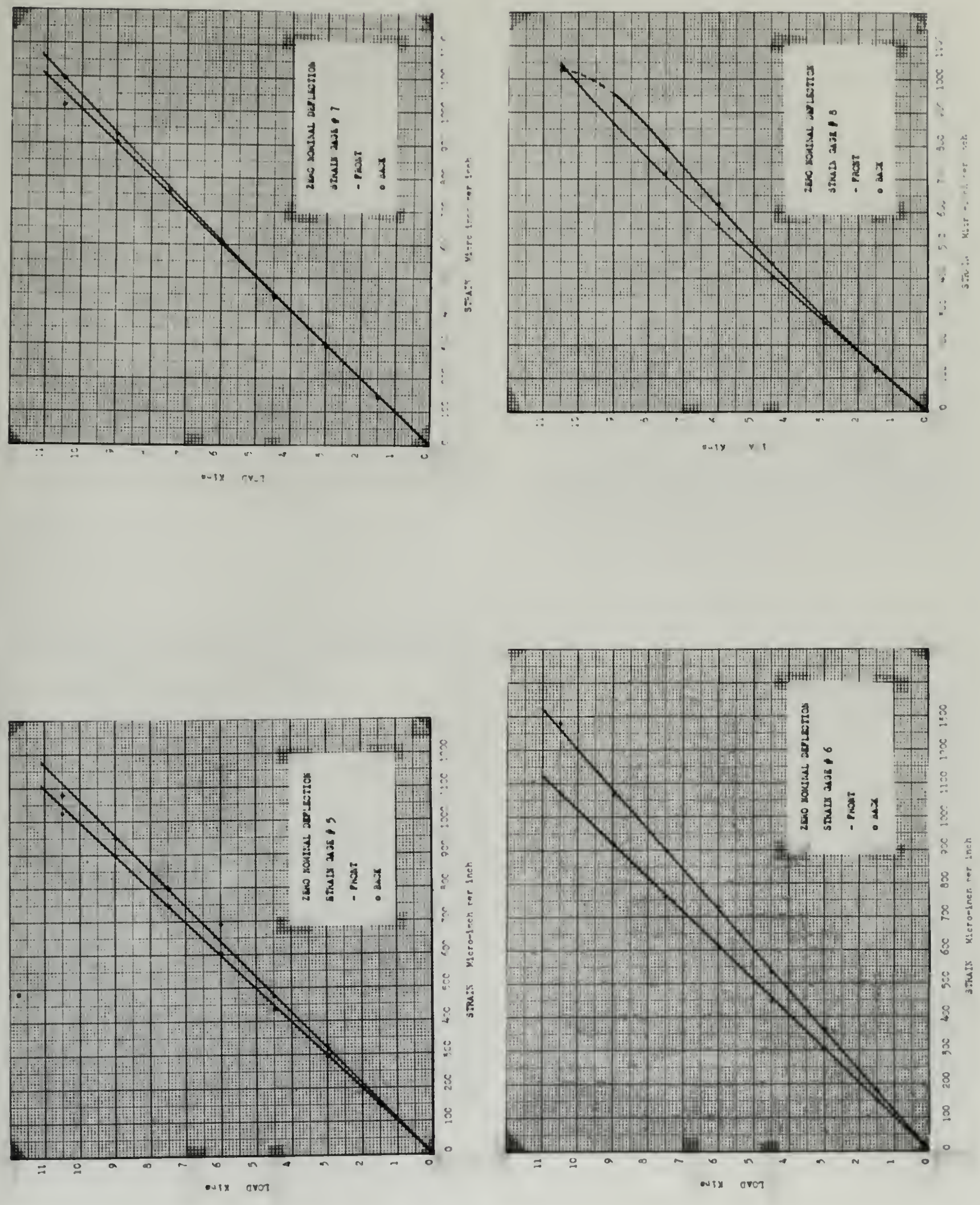
The arithmetical mean average of the strain distribution curve at the mid-depth for each specimen was taken as the average strain in the plate. This value is different from the strain that would be obtained by dividing the load by the product of the cross-sectional area times the modulus of elasticity of the material, assuming that the stiffeners shared the load.

FIGURE XV



ZERO NOMINAL DEFLECTION
STRAIN GAGE # 2
• FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 4
ZERO NOMINAL DEFLECTION
- STRAIN GAGE "A"
o STRAIN GAGE "D"
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 1
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 3
LOAD Kips

FIGURE XVI



ZERO NOMINAL DEFLECTION
STRAIN GAGE # 7
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 8
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 5
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 6
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XVII

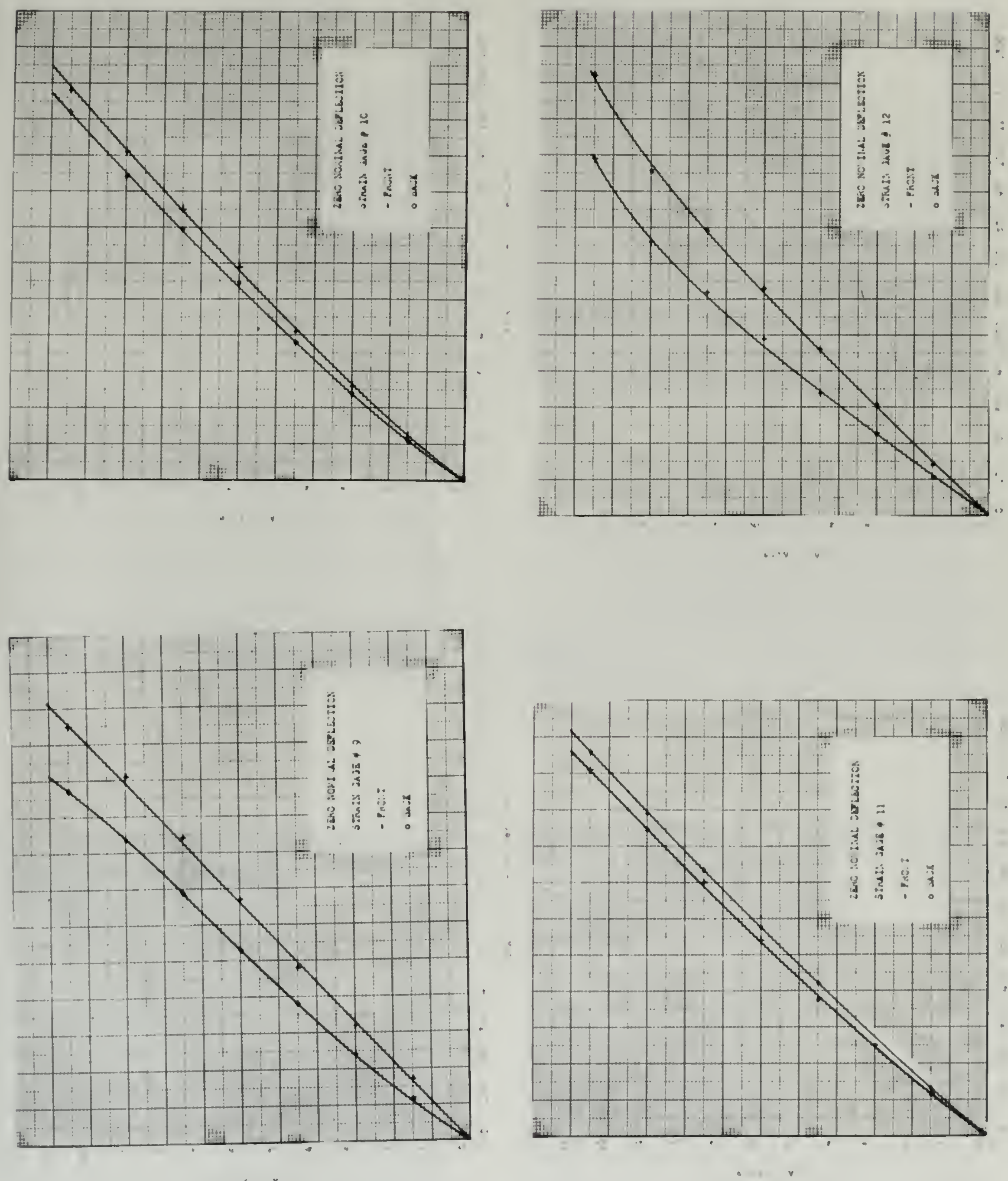

ZERO NOMINAL DEFLECTION
STRAIN GAGE # 10
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 12
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 9
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 11
- FRONT
o BACK

FIGURE XVIII

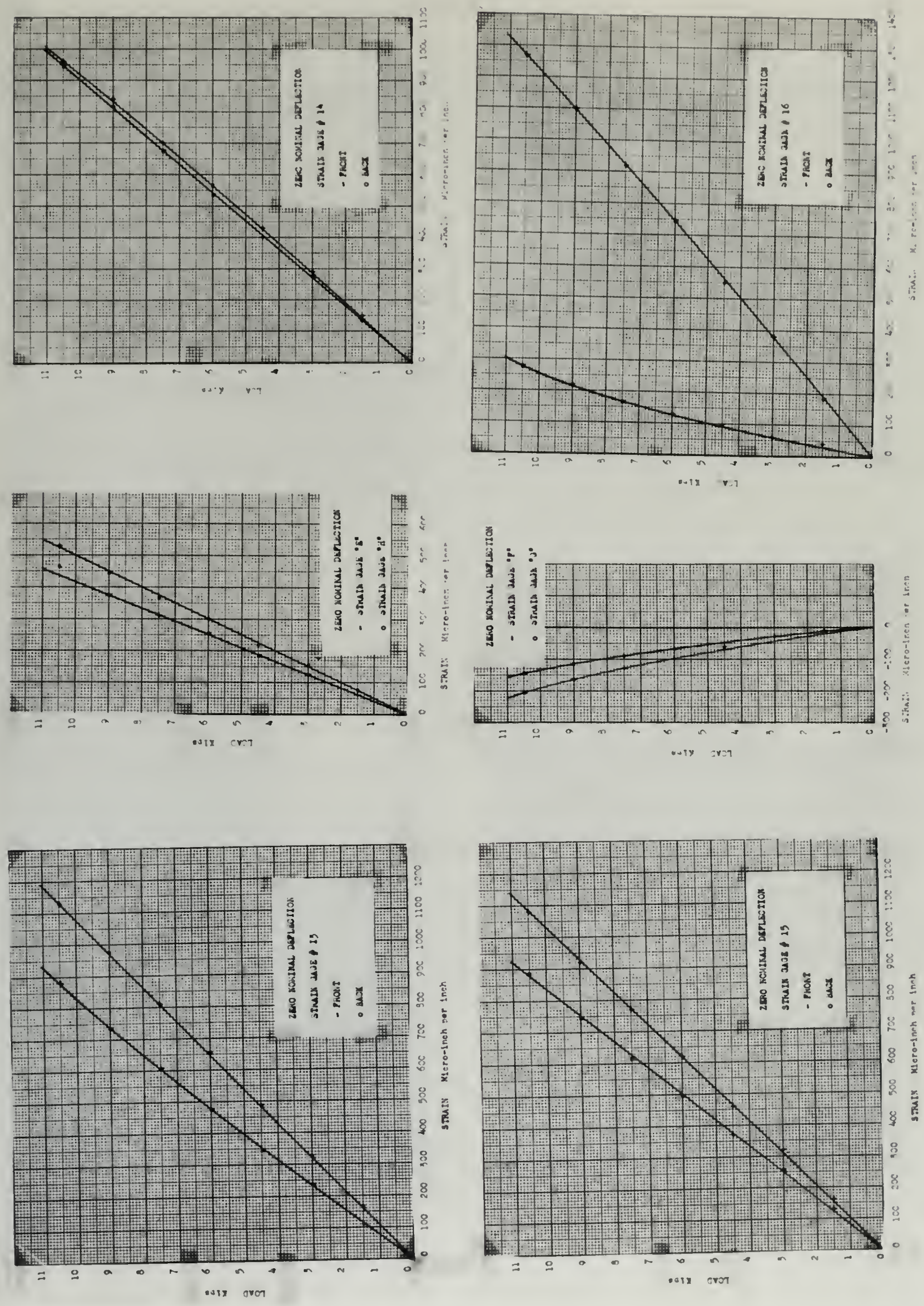
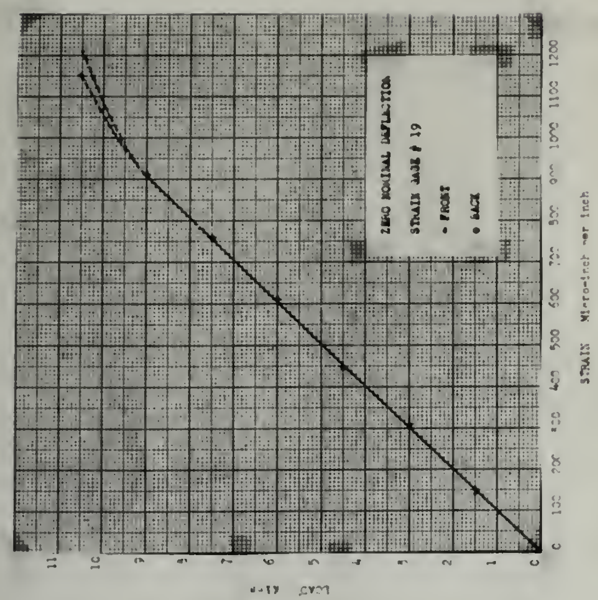
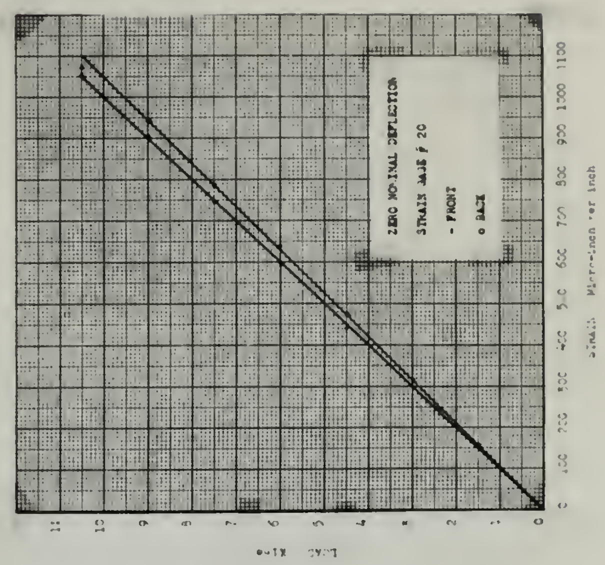
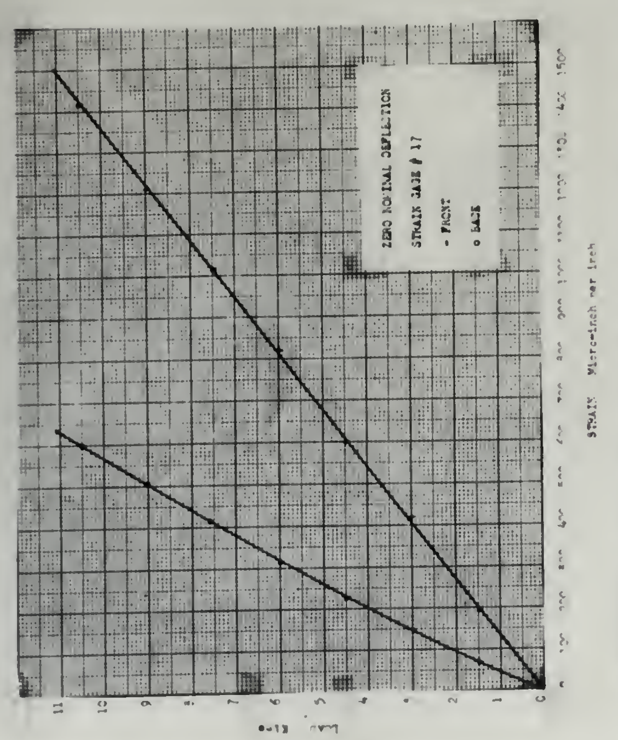


FIGURE XIX


ZERO NOMINAL DEFLECTION
STRAIN GAGE # 19
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips


ZERO NOMINAL DEFLECTION
STRAIN GAGE # 20
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips


ZERO NOMINAL DEFLECTION
STRAIN GAGE # 17
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

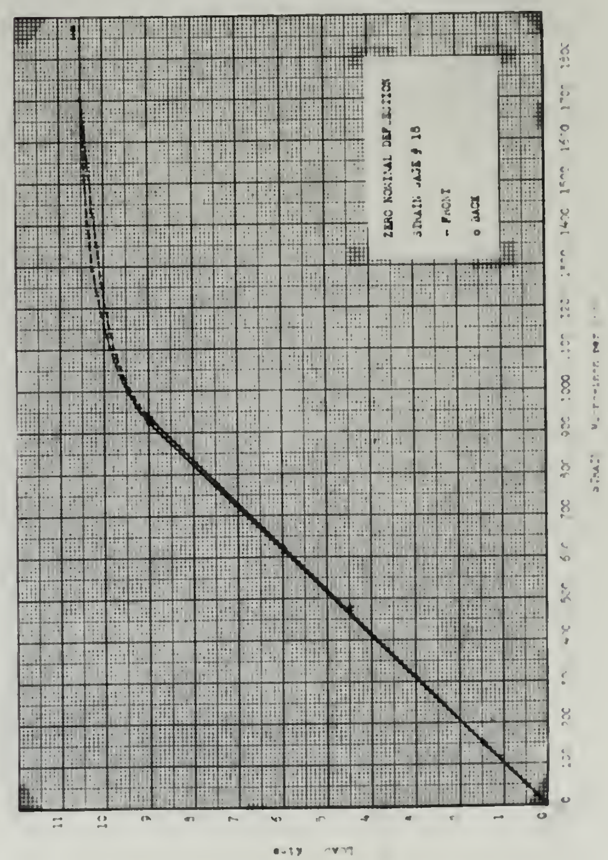

ZERO NOMINAL DEFLECTION
STRAIN GAGE # 18
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XX

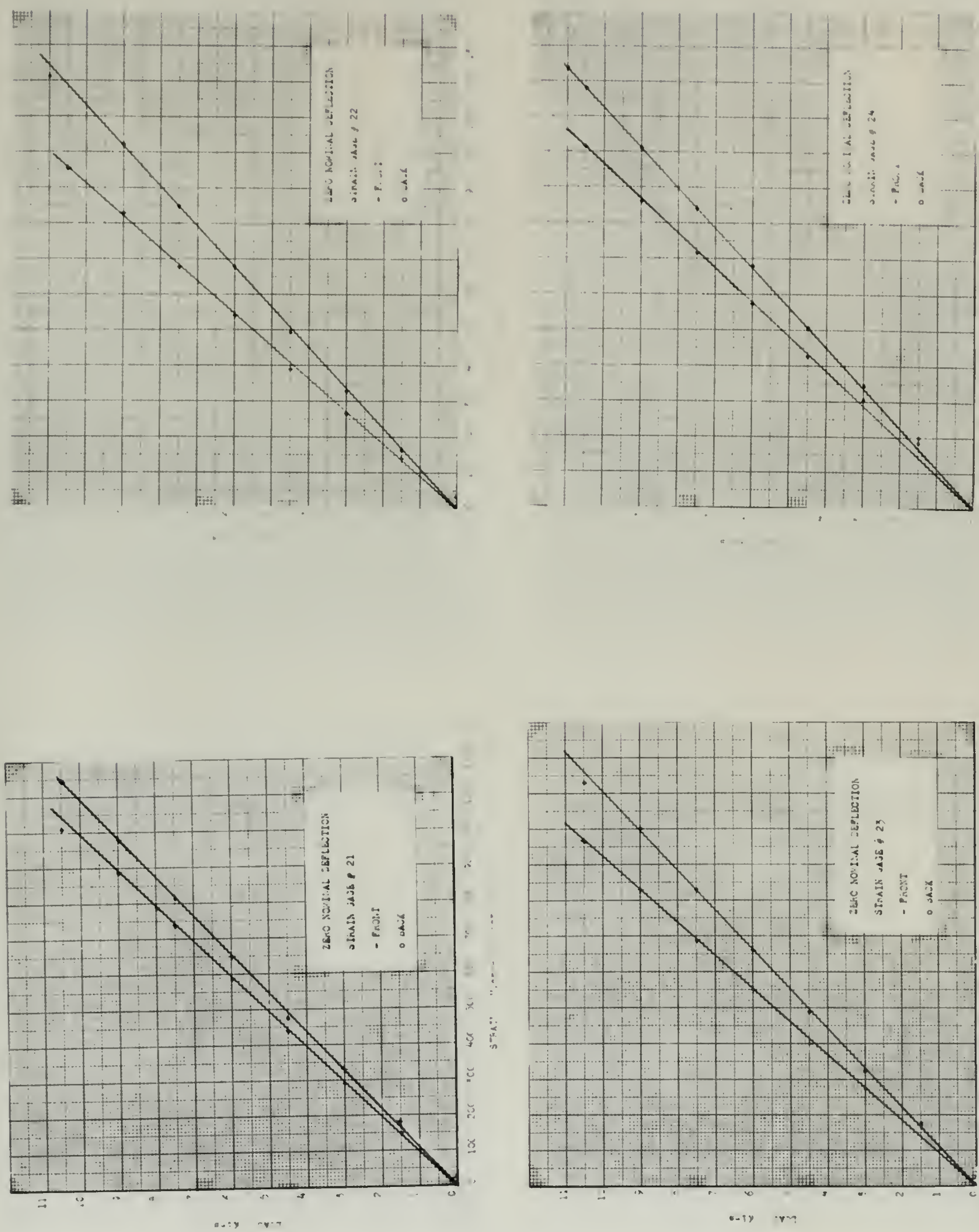

STRAIN GAGE # 22
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 21
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 23
- FRONT
o BACK

FIGURE XXI

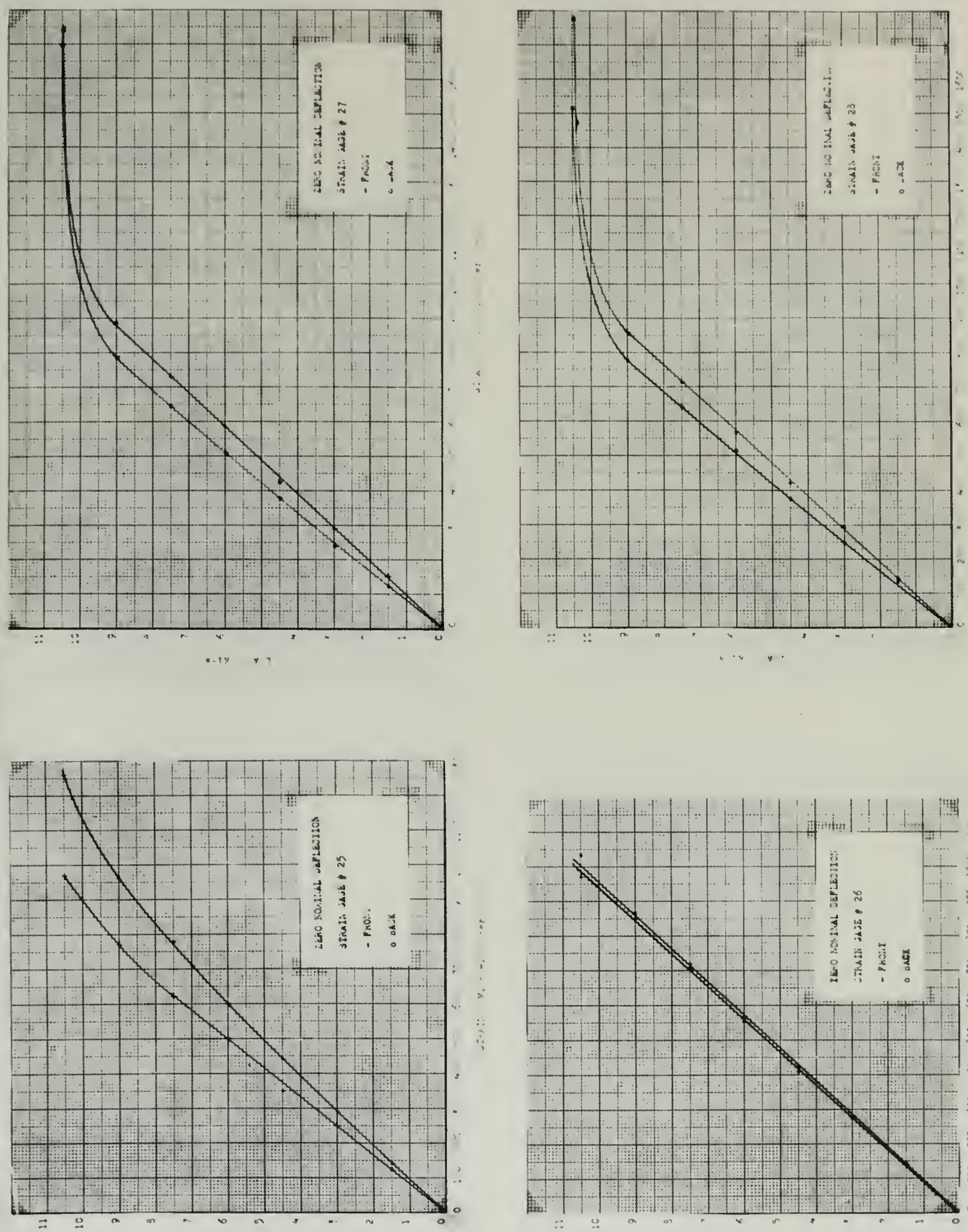

ZERO NOMINAL DEFLECTION
STRAIN GAGE # 27
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 23
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 25
- FRONT
o BACK
ZERO NOMINAL DEFLECTION
STRAIN GAGE # 26
- FRONT
o BACK

FIGURE XXII

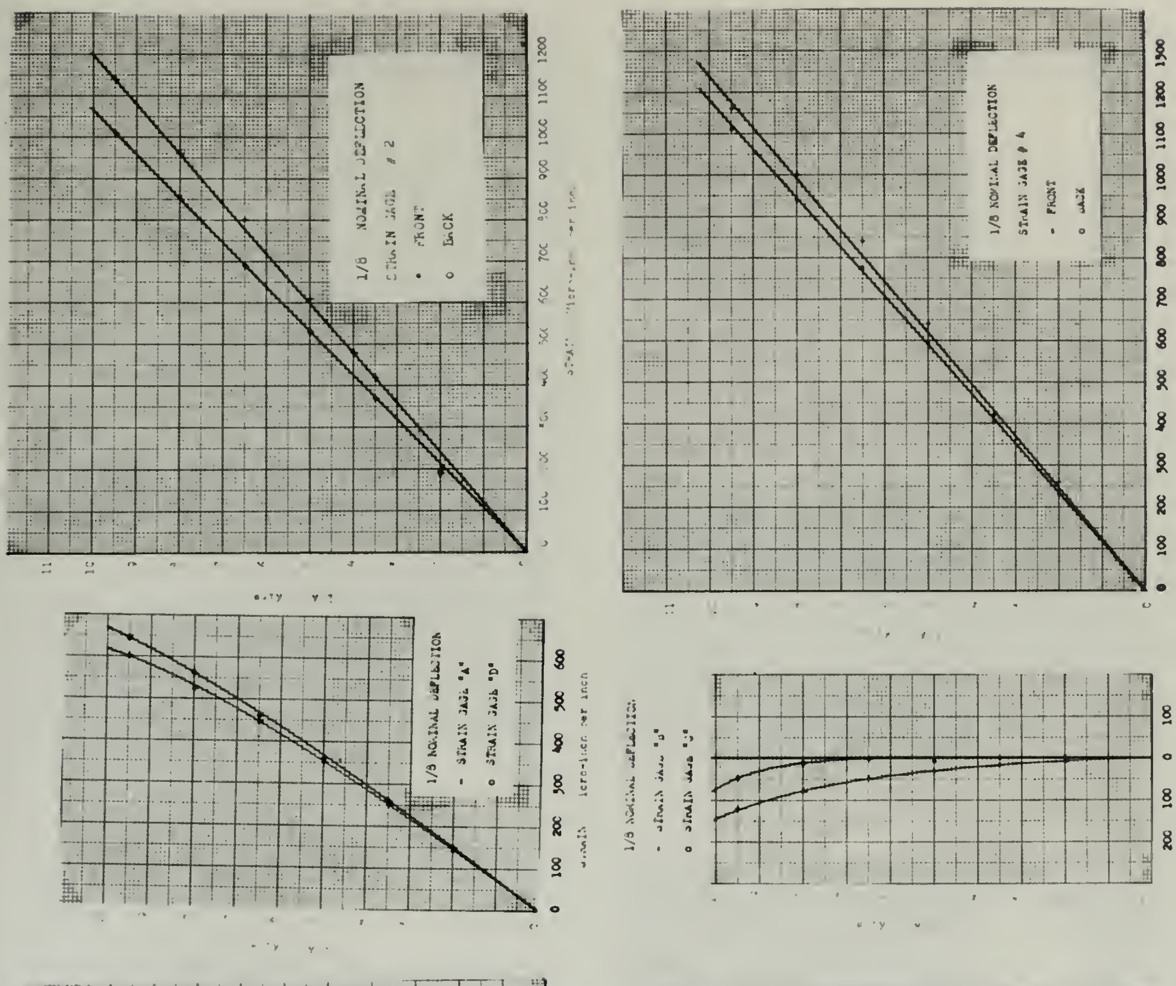

1/8 NOMINAL DEFLECTION
STRAIN GAGE # 2
FRONT
BACK
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 4
FRONT
BACK
1/8 NOMINAL DEFLECTION
STRAIN GAGE "A"
STRAIN GAGE "D"
STRAIN Micro-inch per inch

FIGURE XXIII

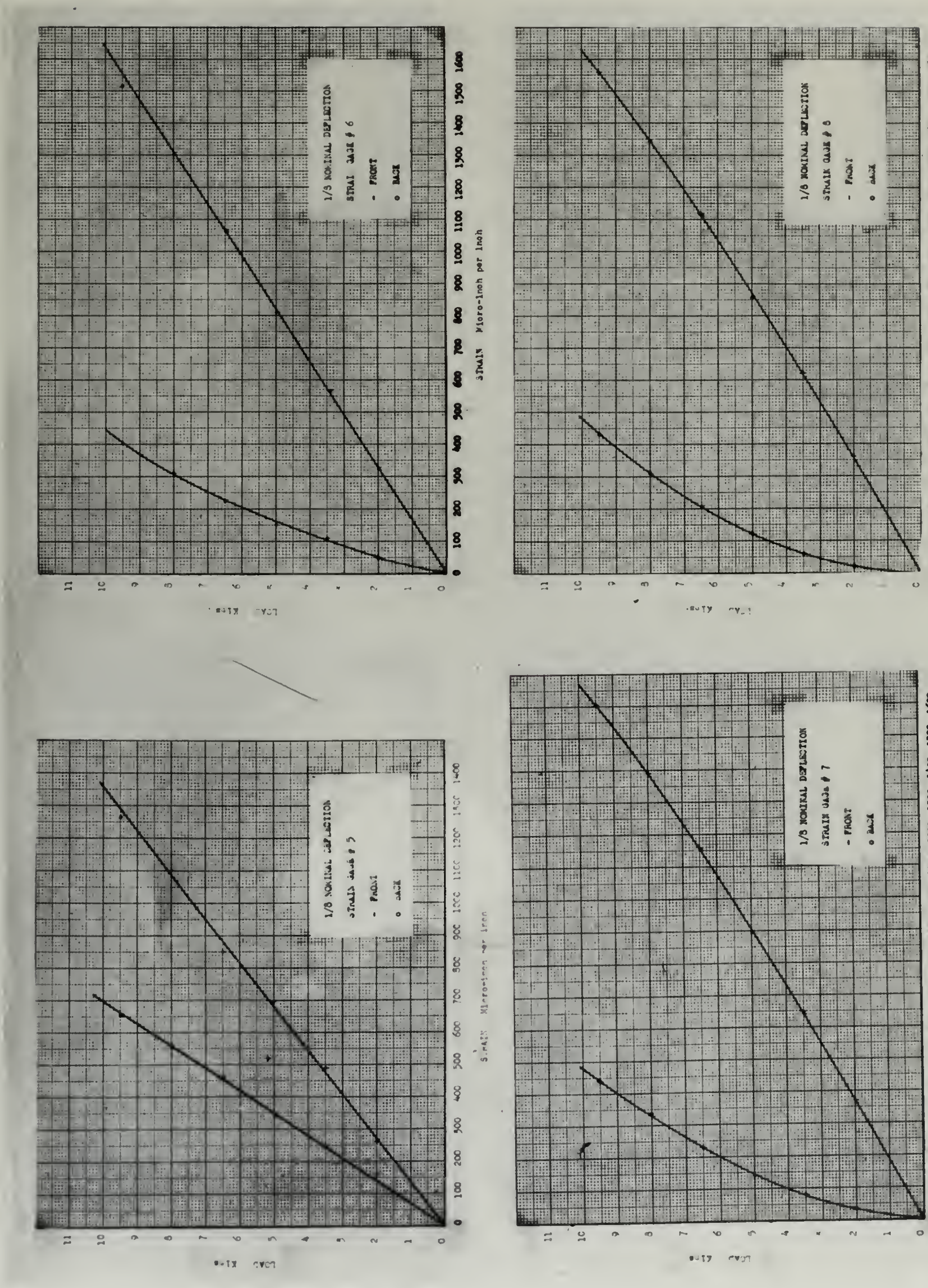


FIGURE XXIV

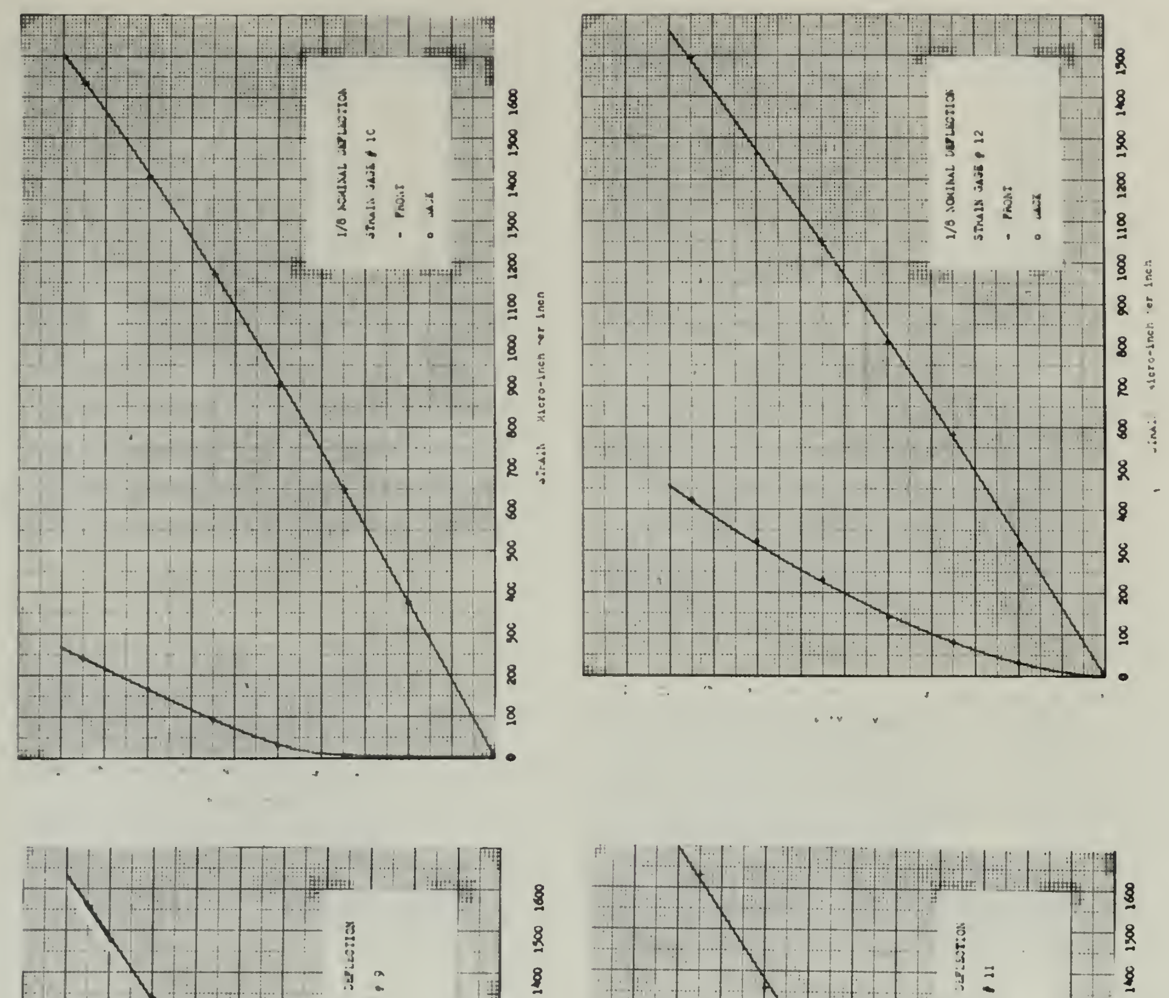

1/8 NOMINAL DEFLECTION
STRAIN GAGE # 10
- FRONT
o BACK
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 12
- FRONT
o BACK
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 9
- FRONT
o BACK
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 11
- FRONT
o BACK
STRAIN Micro-inch per inch

FIGURE XXV

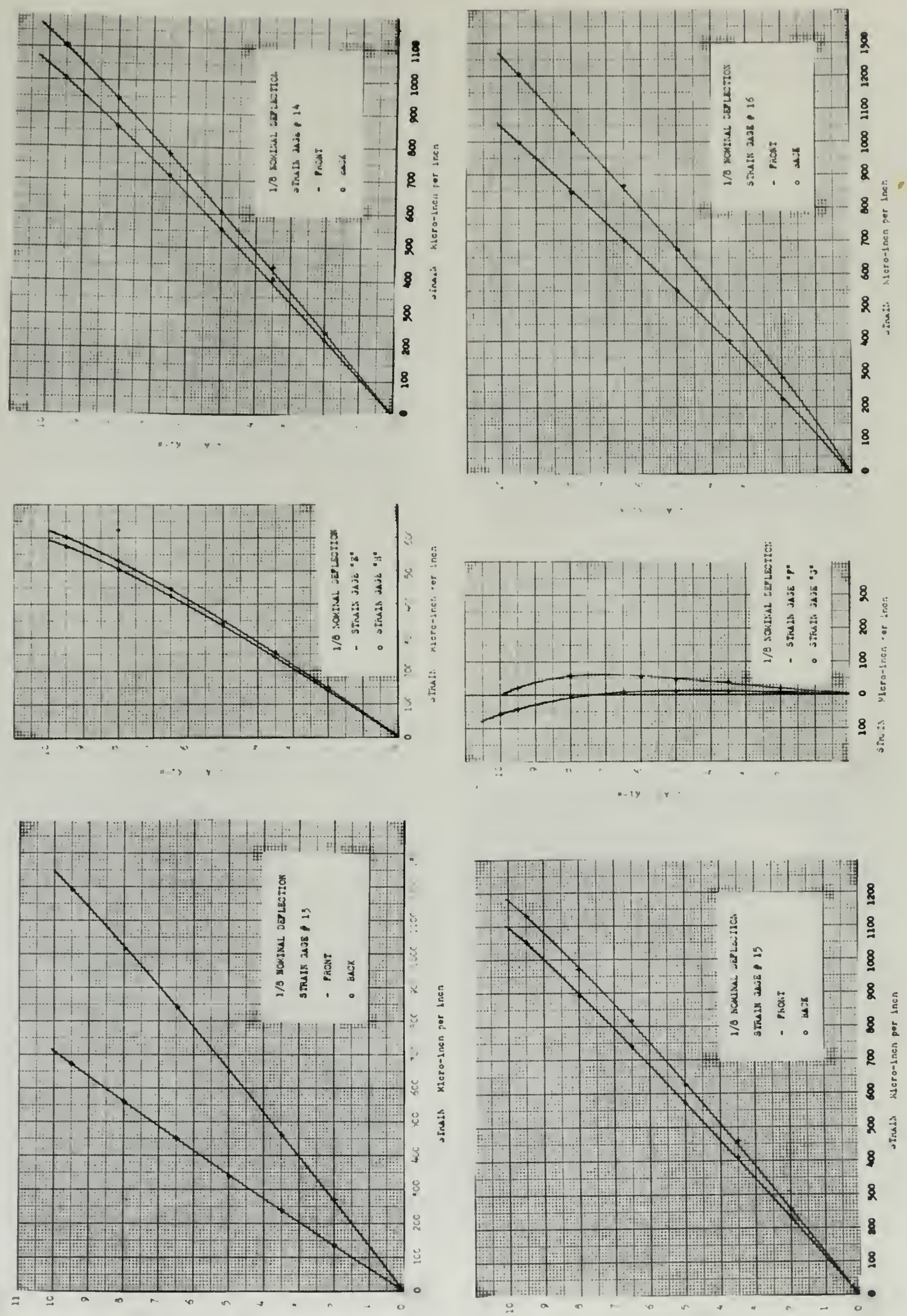
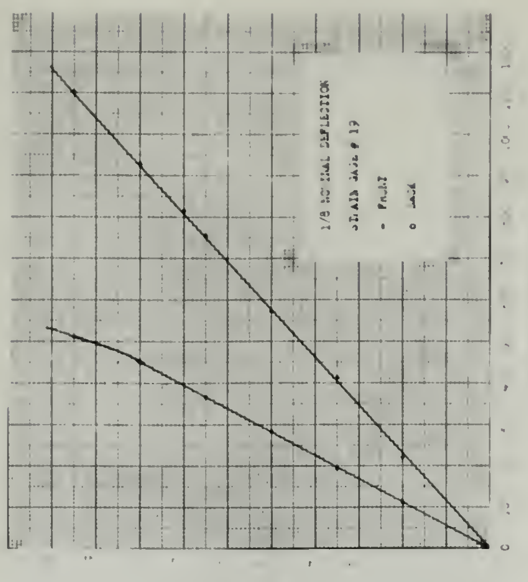
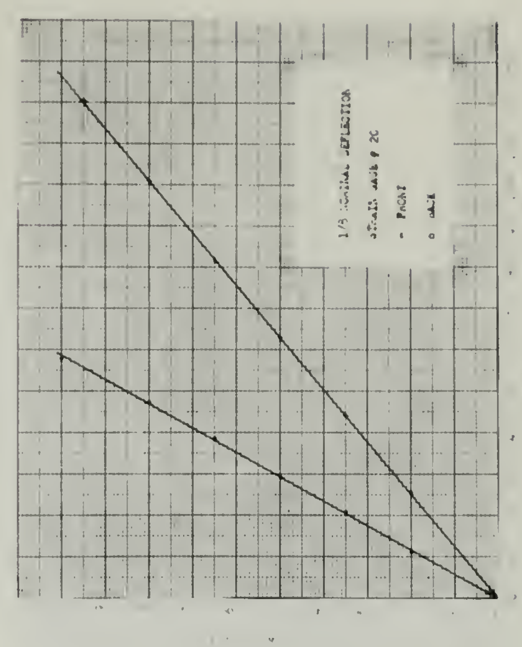
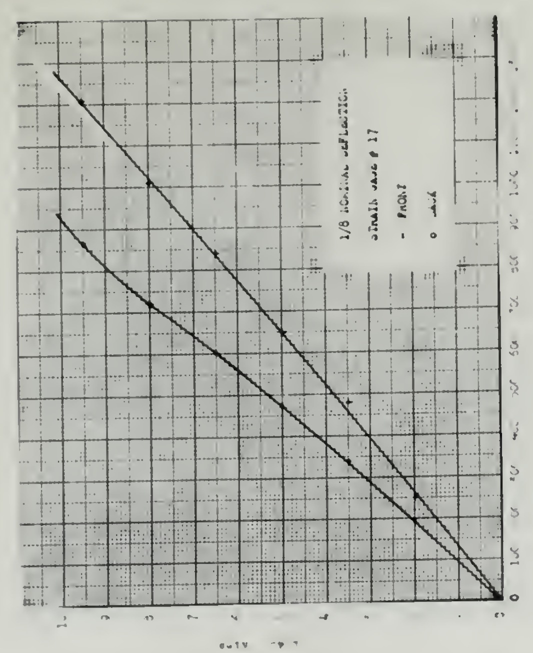

1/8 NOMINAL DEFLECTION
STRAIN GAGE # 14
- FRONT
o BACK
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 16
- FRONT
o BACK
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
- STRAIN GAGE "E"
o STRAIN GAGE "H"
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
- STRAIN GAGE "F"
o STRAIN GAGE "G"
STRAIN Micro-inch per inch
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 13
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD KIPS
1/8 NOMINAL DEFLECTION
STRAIN GAGE # 15
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD KIPS

FIGURE XXVI


1/8 NOMINAL DEFLECTION
STRAIN GAGE # 19
- FRONT
o BACK


1/8 NOMINAL DEFLECTION
STRAIN GAGE # 20
- FRONT
o BACK


1/8 NOMINAL DEFLECTION
STRAIN GAGE # 17
- FRONT
o BACK

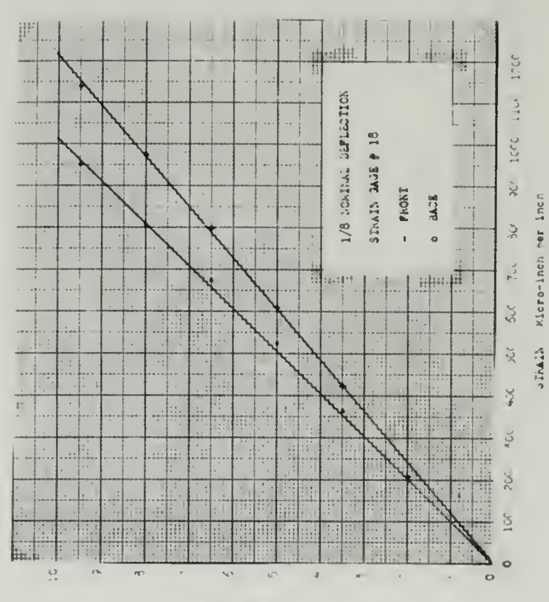

1/8 NOMINAL DEFLECTION
STRAIN GAGE # 18
- FRONT
o BACK
STRAIN Micro-inch per inch

FIGURE XXVII

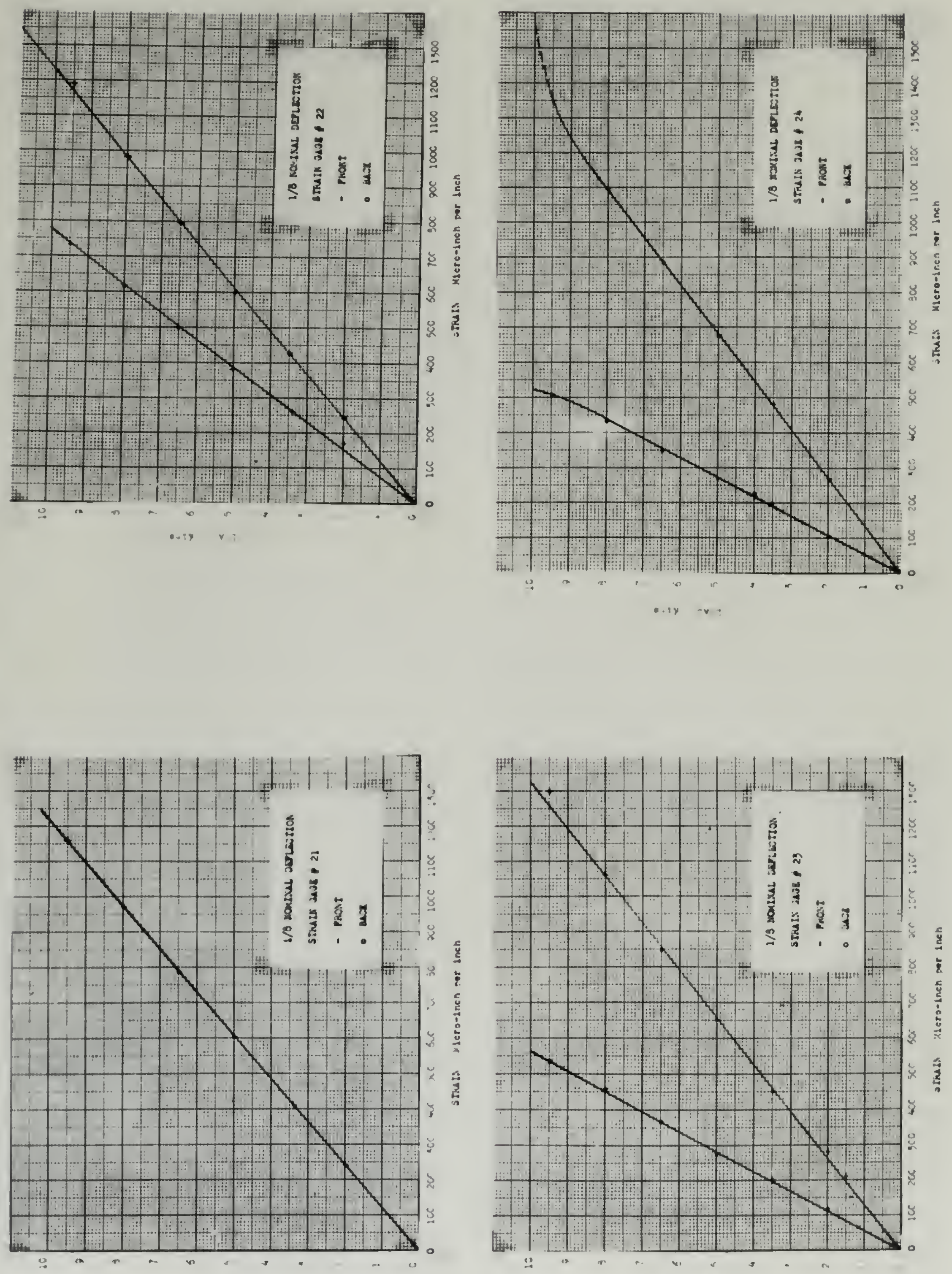


FIGURE XXVIII

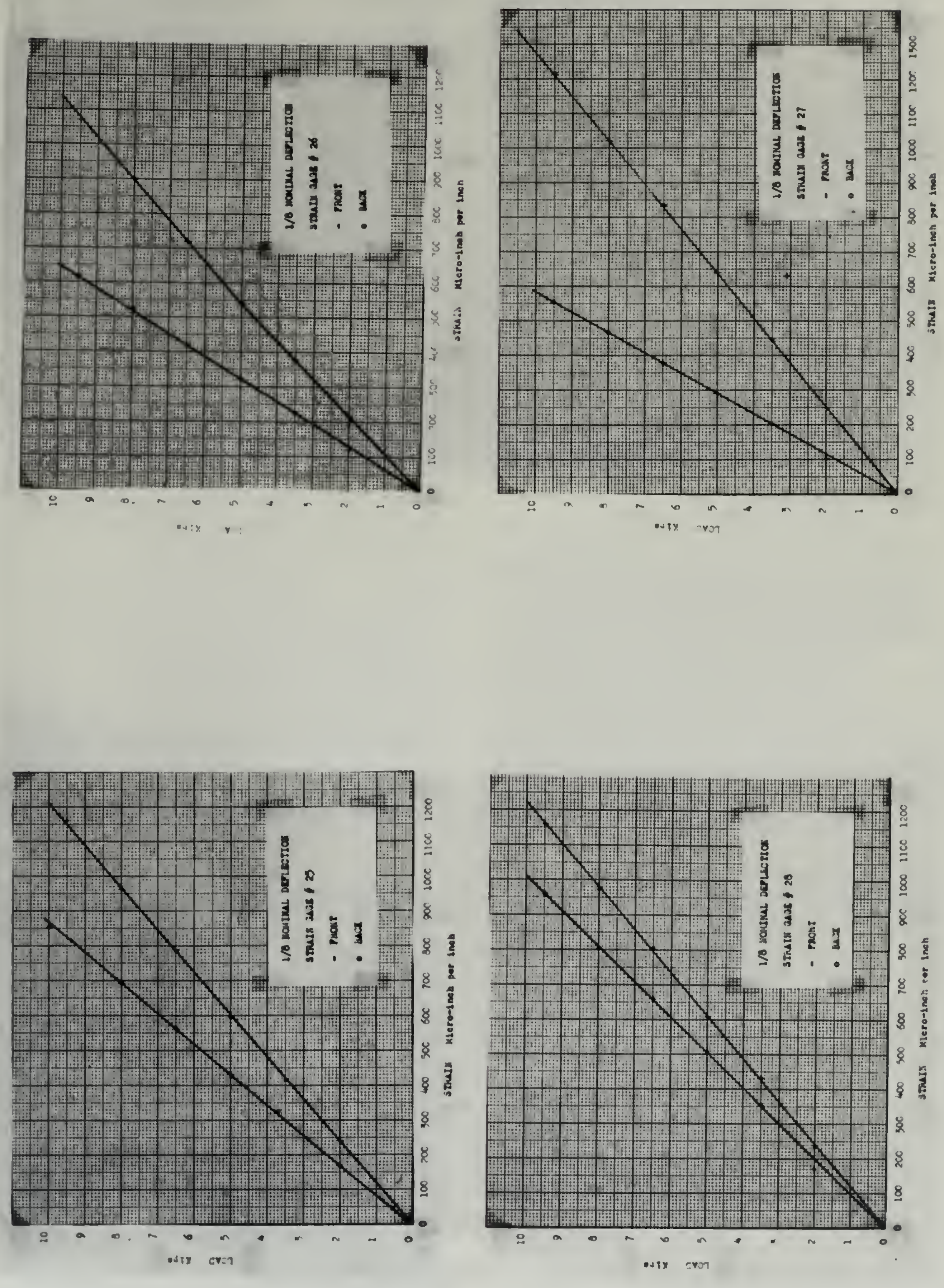


FIGURE XXIX

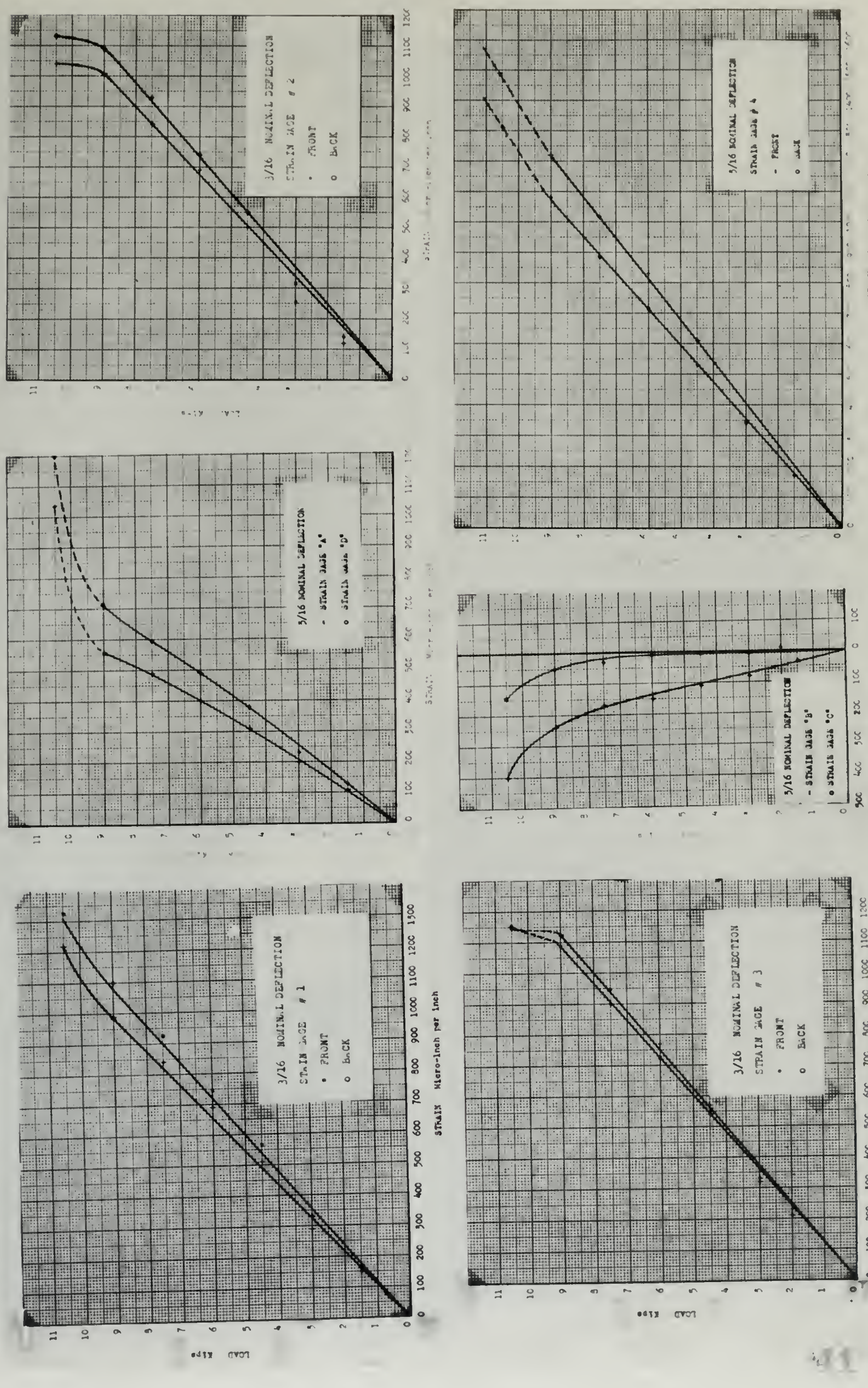

3/16 NOMINAL DEFLECTION
STRAIN GAGE # 2
• FRONT
o BACK
5/16 NOMINAL DEFLECTION
- STRAIN GAGE "A"
o STRAIN GAGE "D"
3/16 NOMINAL DEFLECTION
STRAIN GAGE # 1
• FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 4
- FRONT
o BACK
5/16 NOMINAL DEFLECTION
- STRAIN GAGE "B"
o STRAIN GAGE "C"
3/16 NOMINAL DEFLECTION
STRAIN GAGE # 3
• FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XXX

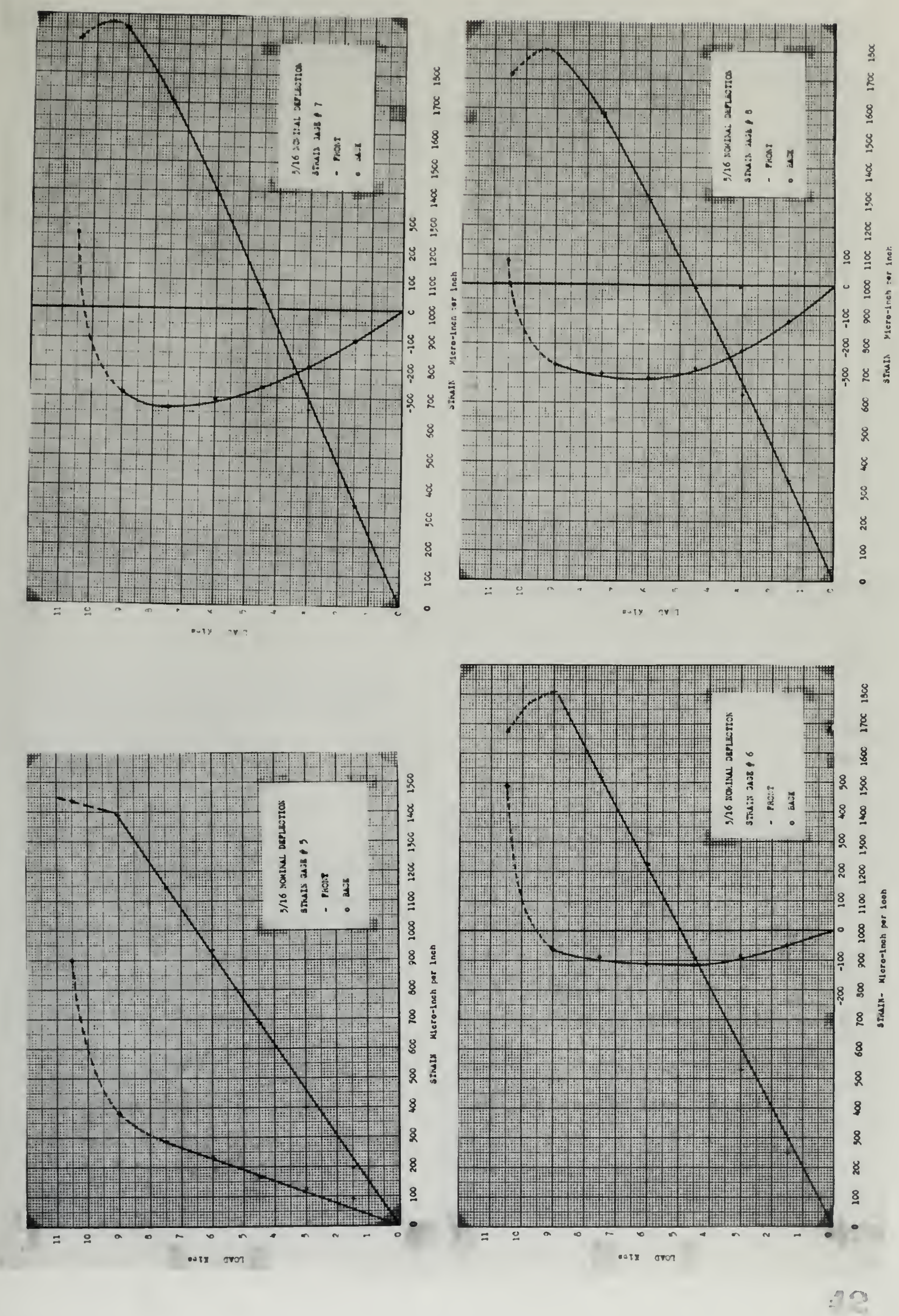
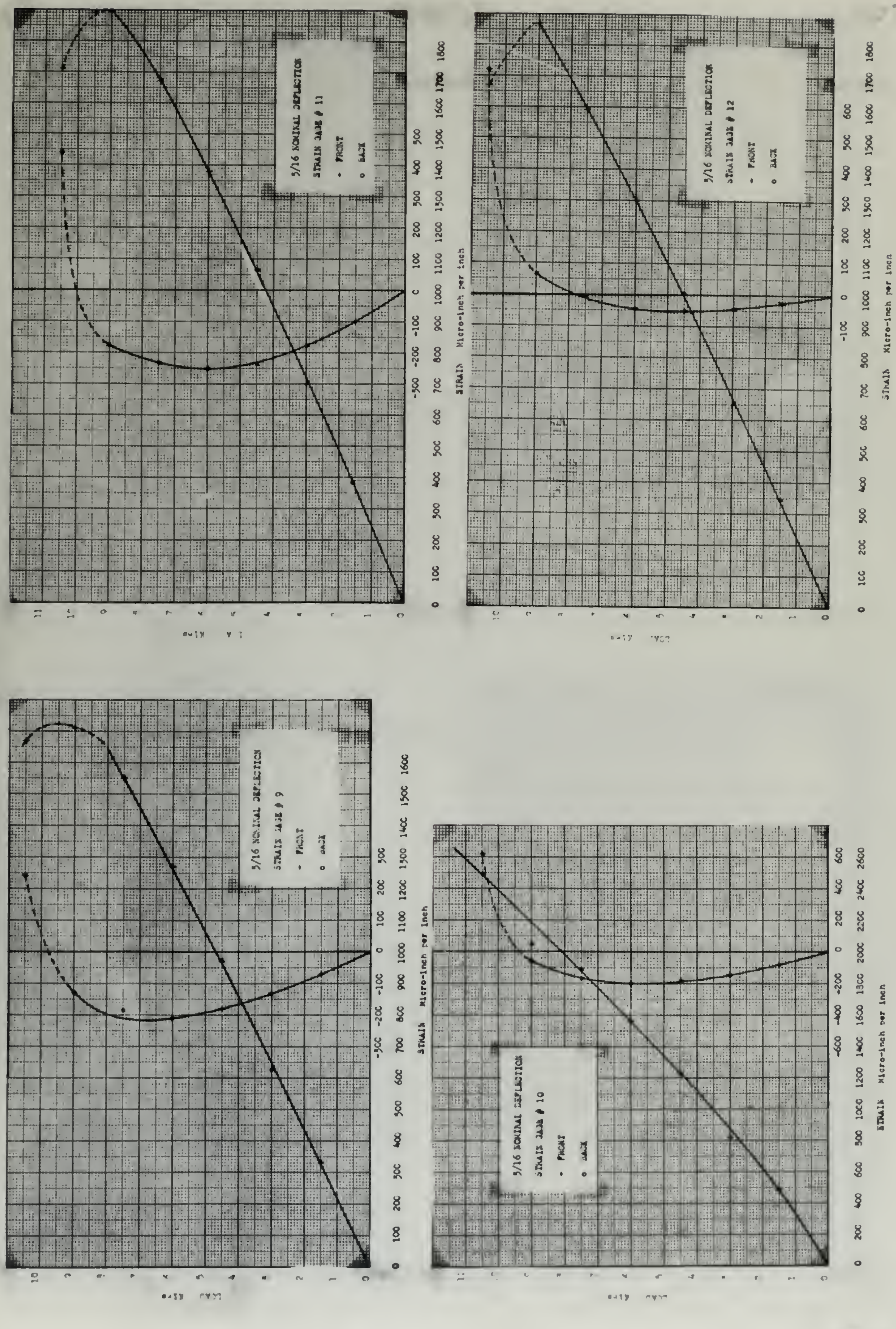
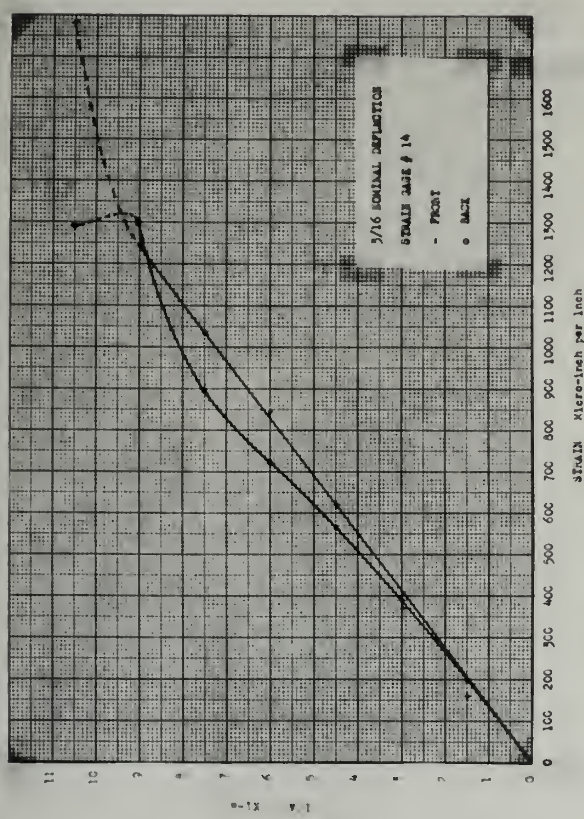

5/16 NOMINAL DEFLECTION
STRAIN GAGE # 7
- FRONT
o BACK
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 8
- FRONT
o BACK
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 5
- FRONT
o BACK
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 6
- FRONT
o BACK
LOAD Kips
STRAIN Micro-inch per inch

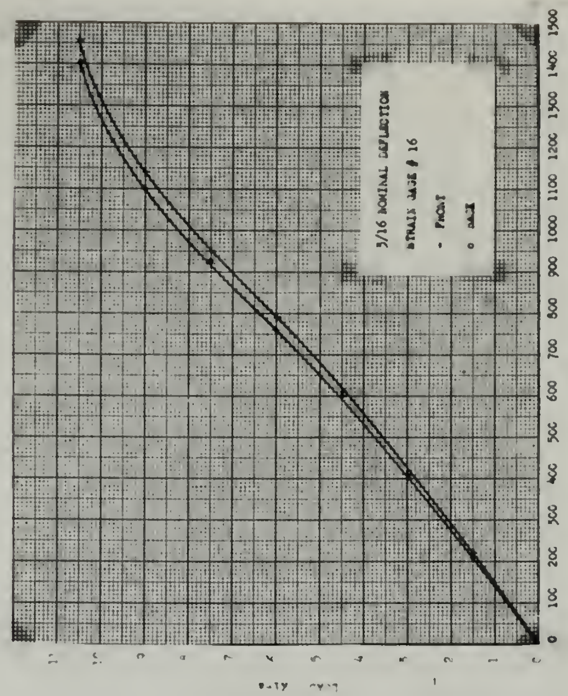
FIGURE XXXI

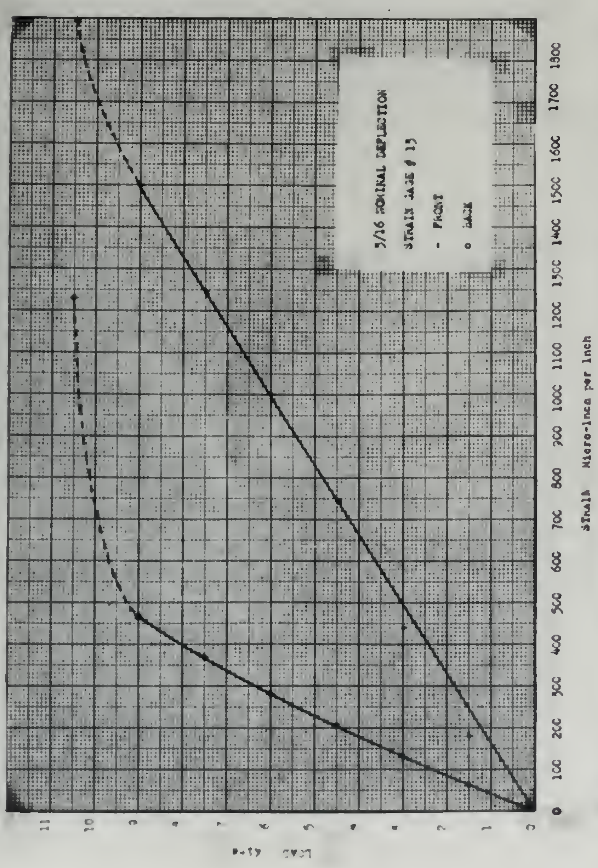


5/16 NOMINAL DEFLECTION
STRAIN GAGE # 11
- FRONT
o BACK
STRAIN Micro-inch per inch
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 12
- FRONT
o BACK
STRAIN Micro-inch per inch
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 9
- FRONT
o BACK
STRAIN Micro-inch per inch
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 10
- FRONT
o BACK
STRAIN Micro-inch per inch

FIGURE XXXII







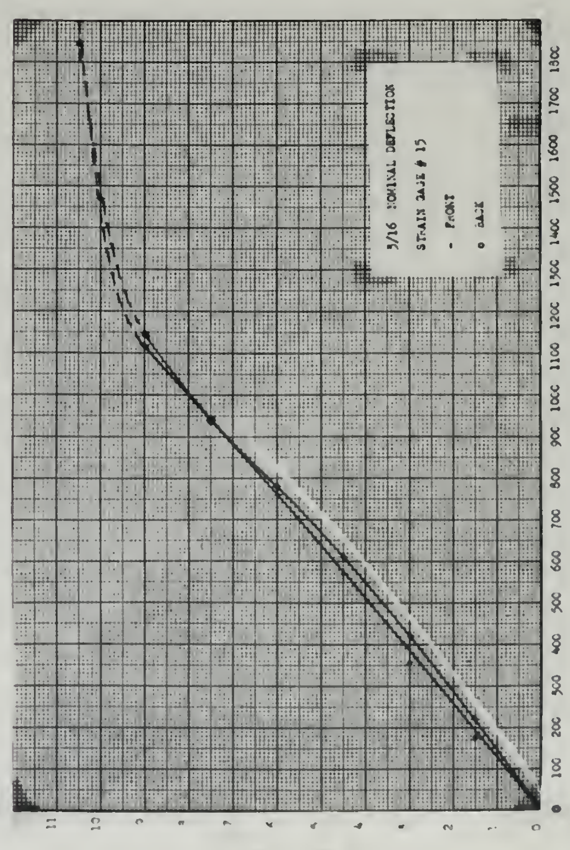


FIGURE XXXIII

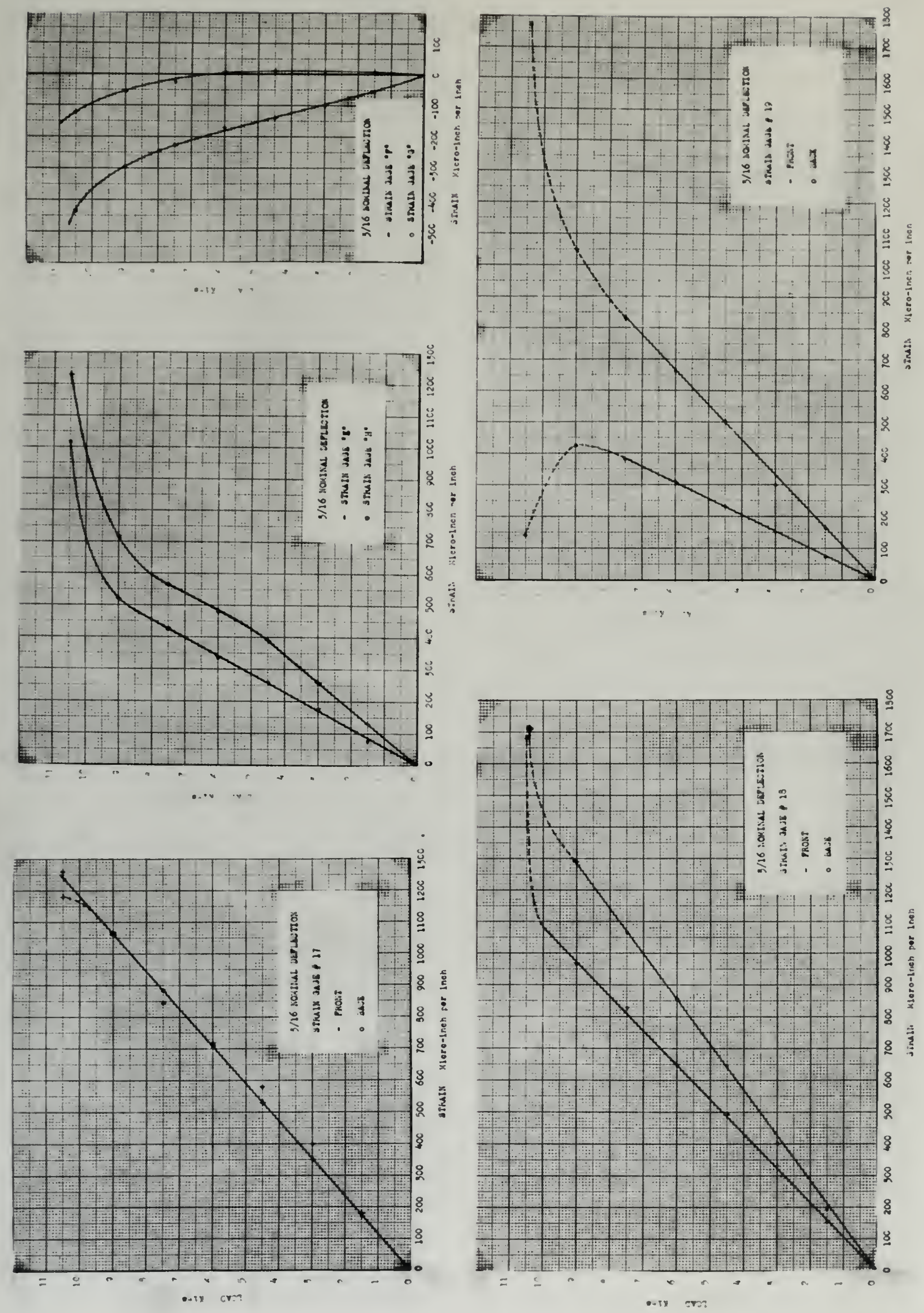


FIGURE XXXIV

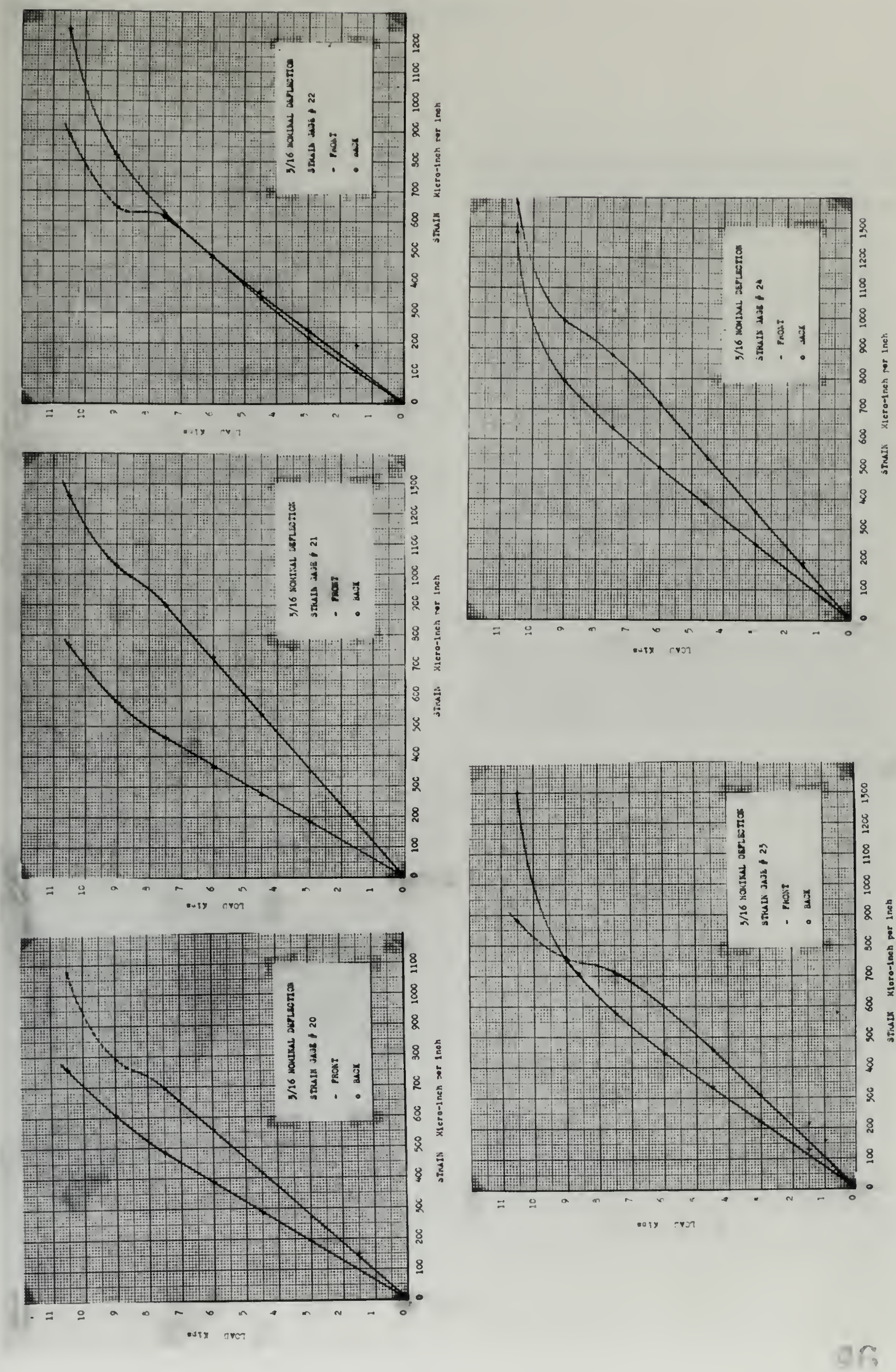


FIGURE XXXV

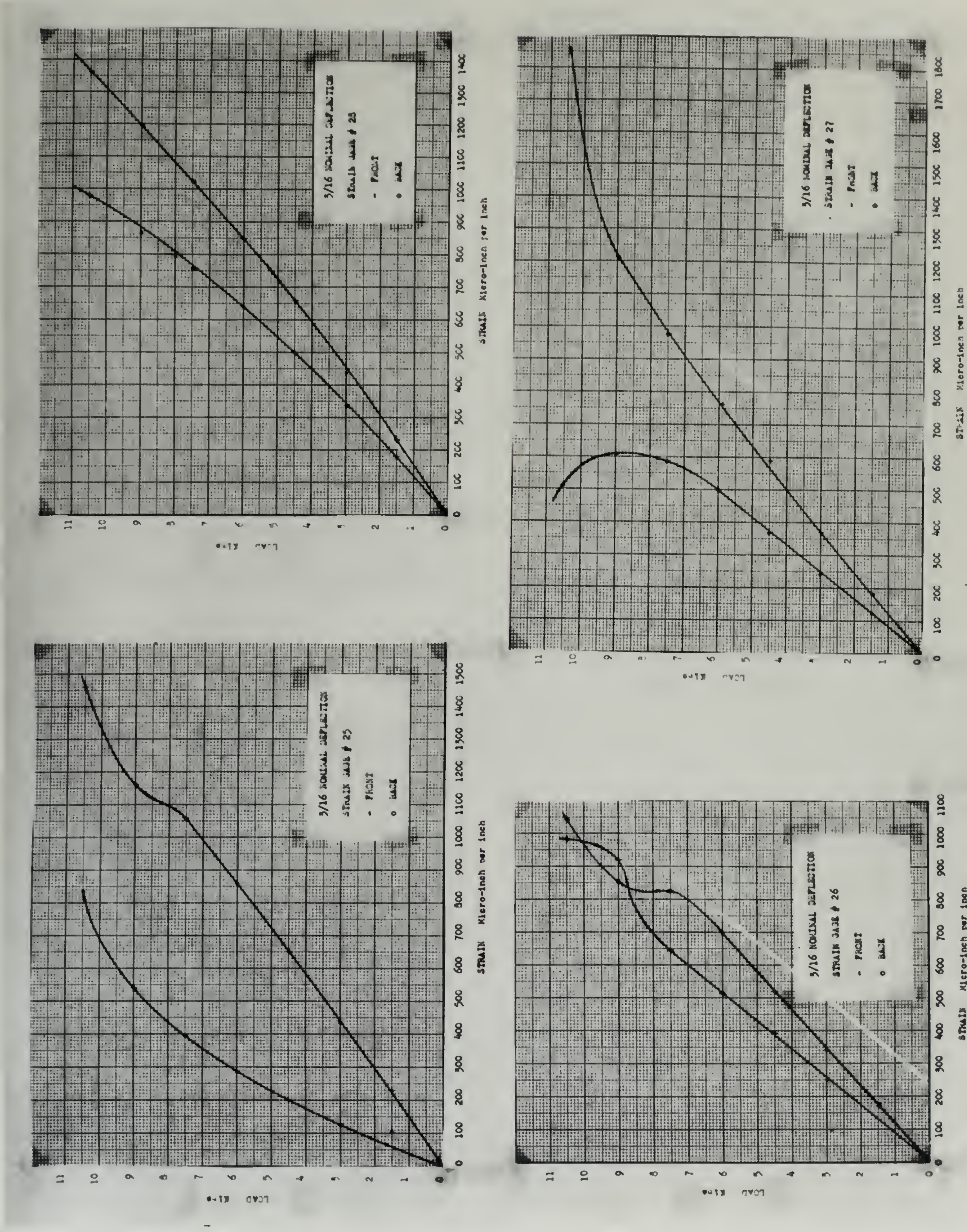

5/16 NOMINAL DEFLECTION
STRAIN GAGE # 28
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 27
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 25
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
5/16 NOMINAL DEFLECTION
STRAIN GAGE # 26
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XXXVI

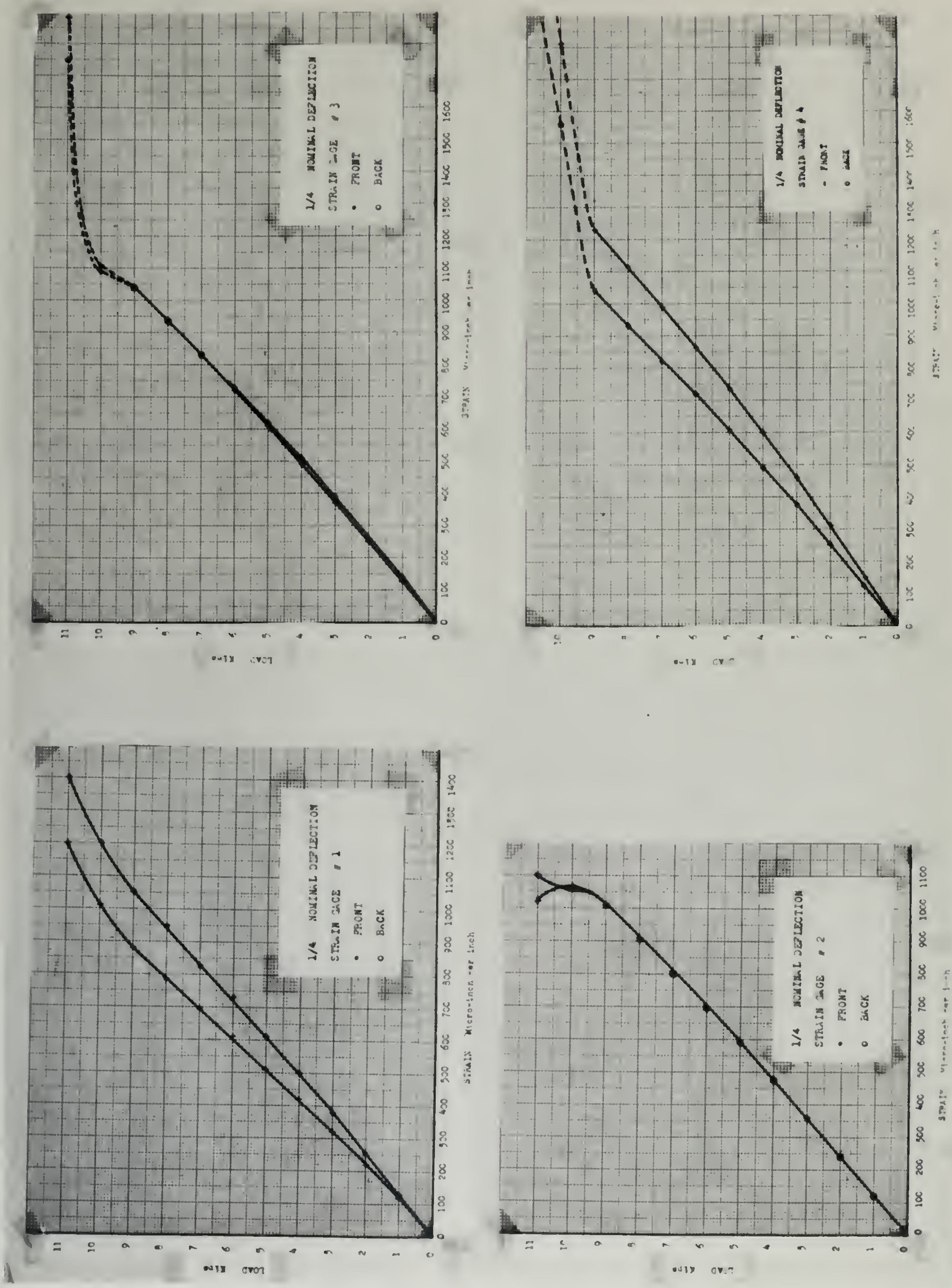


FIGURE XXXVII

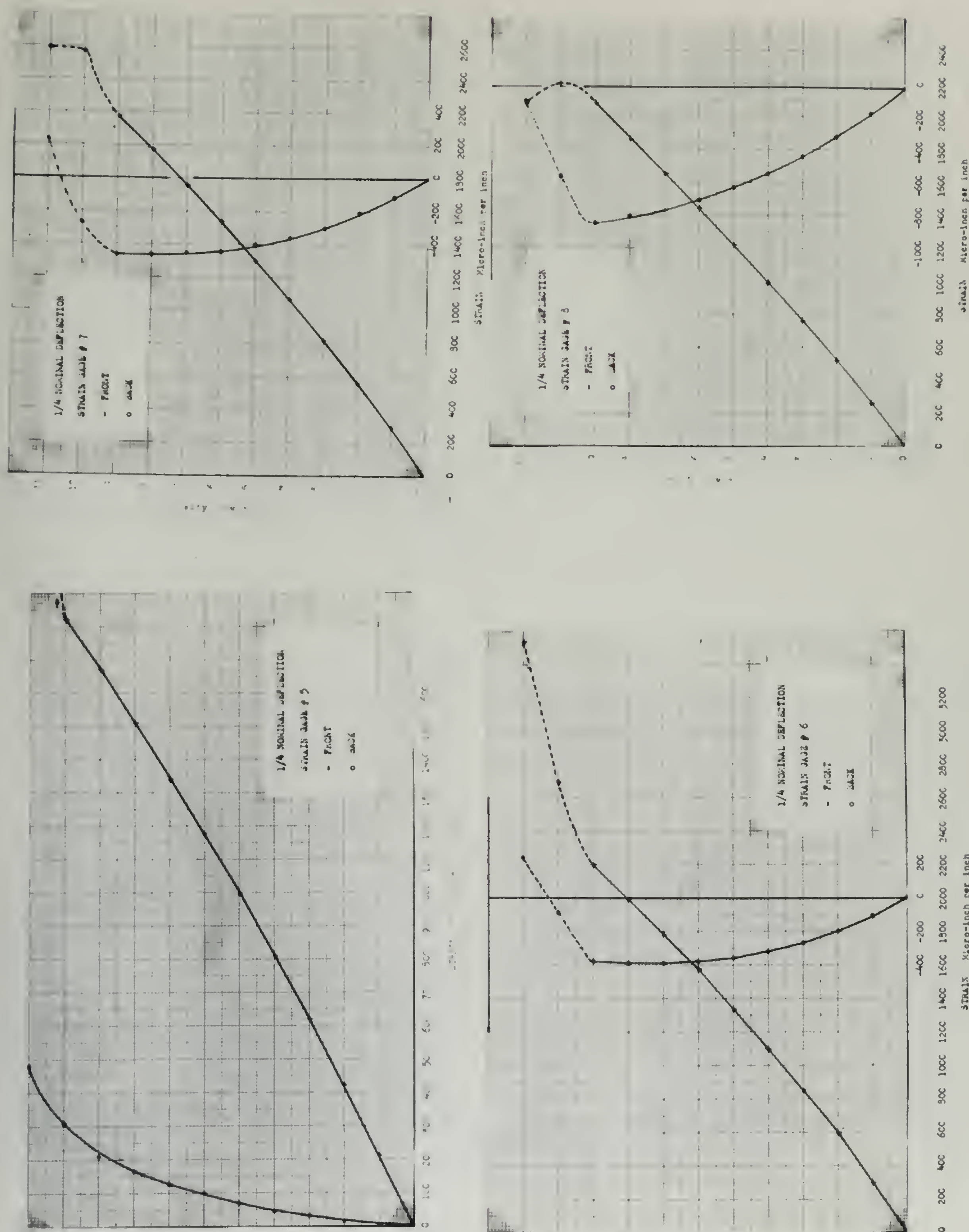


FIGURE XXXVIII

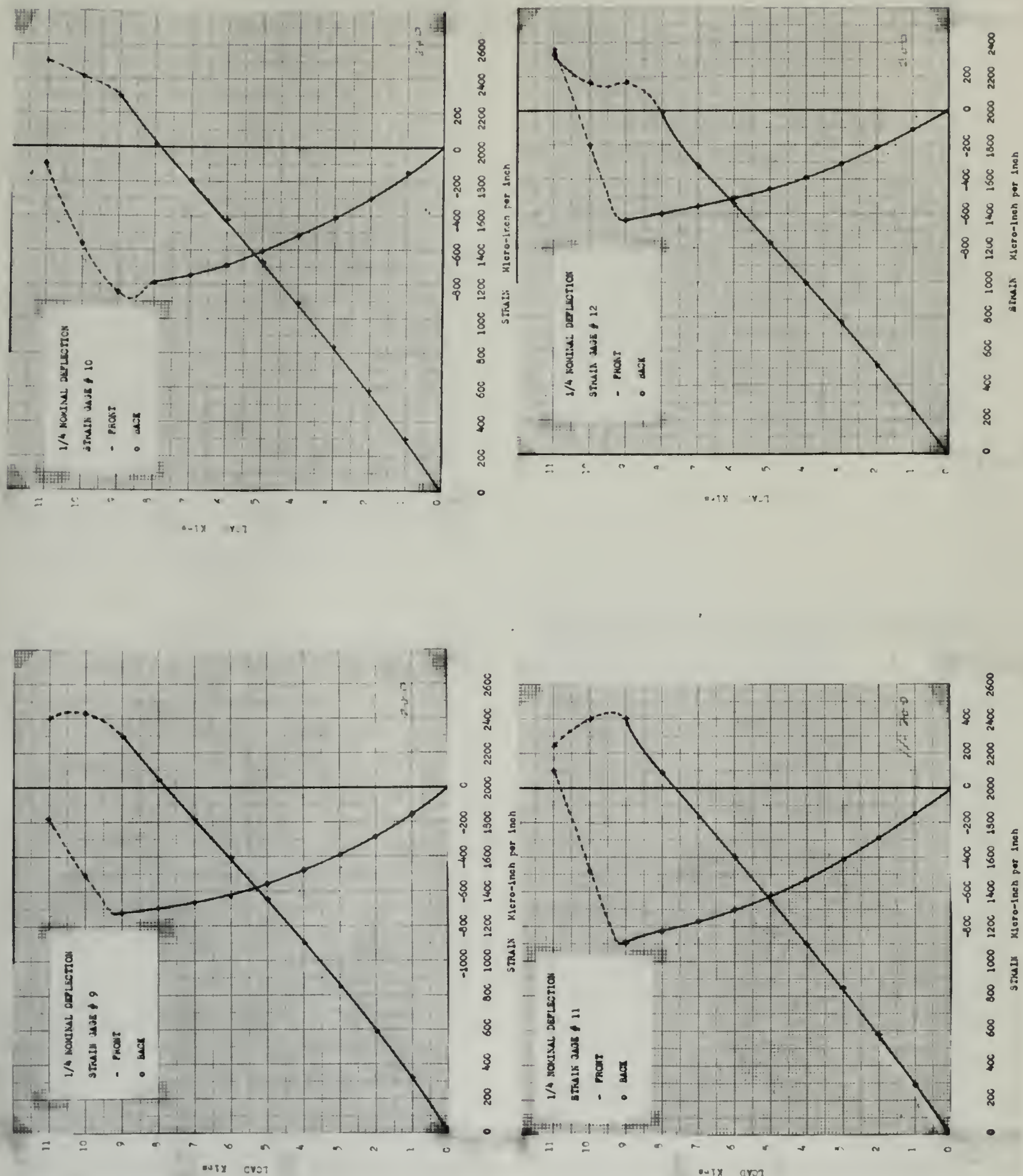


FIGURE XXXIX

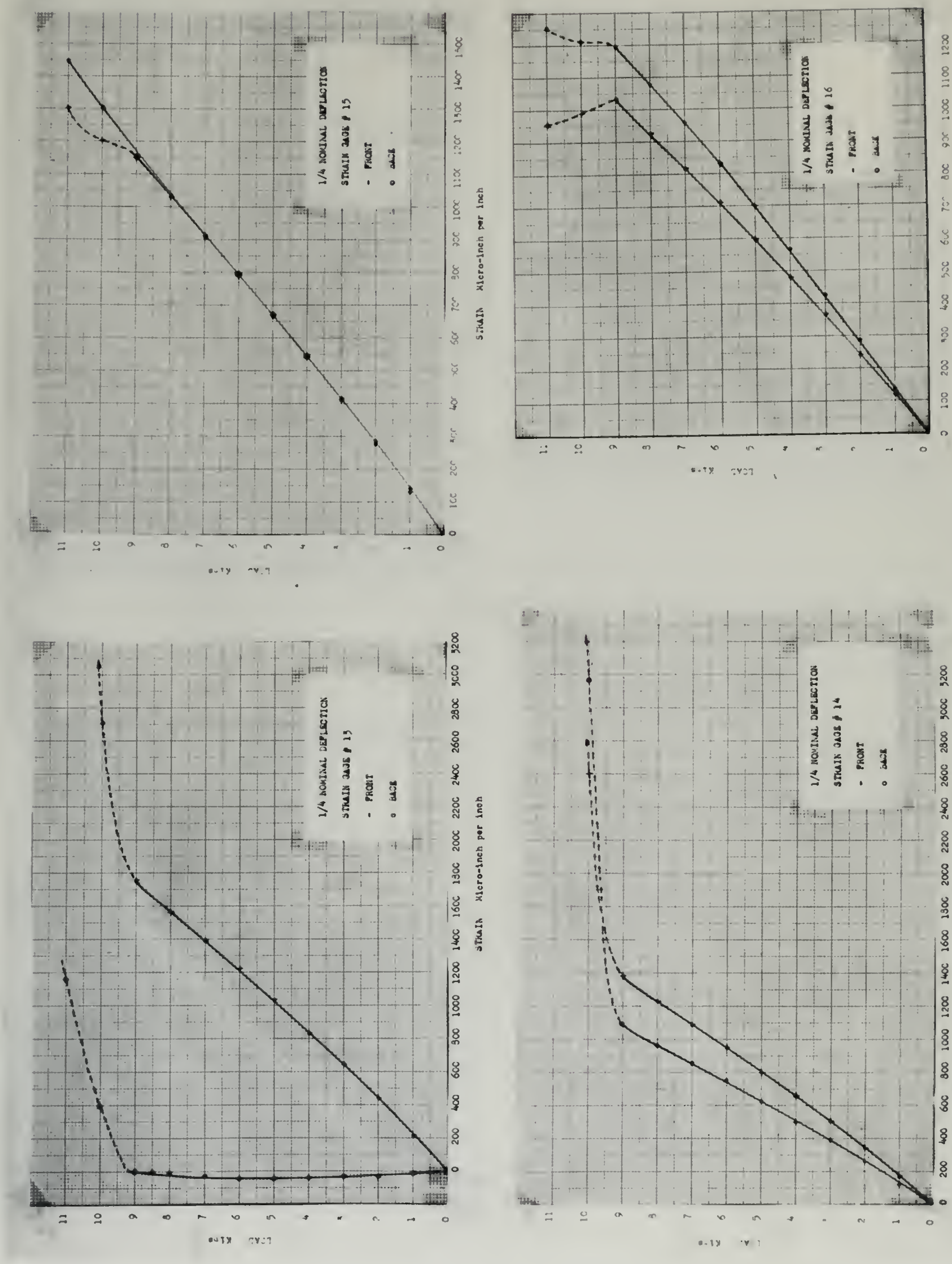


FIGURE XL

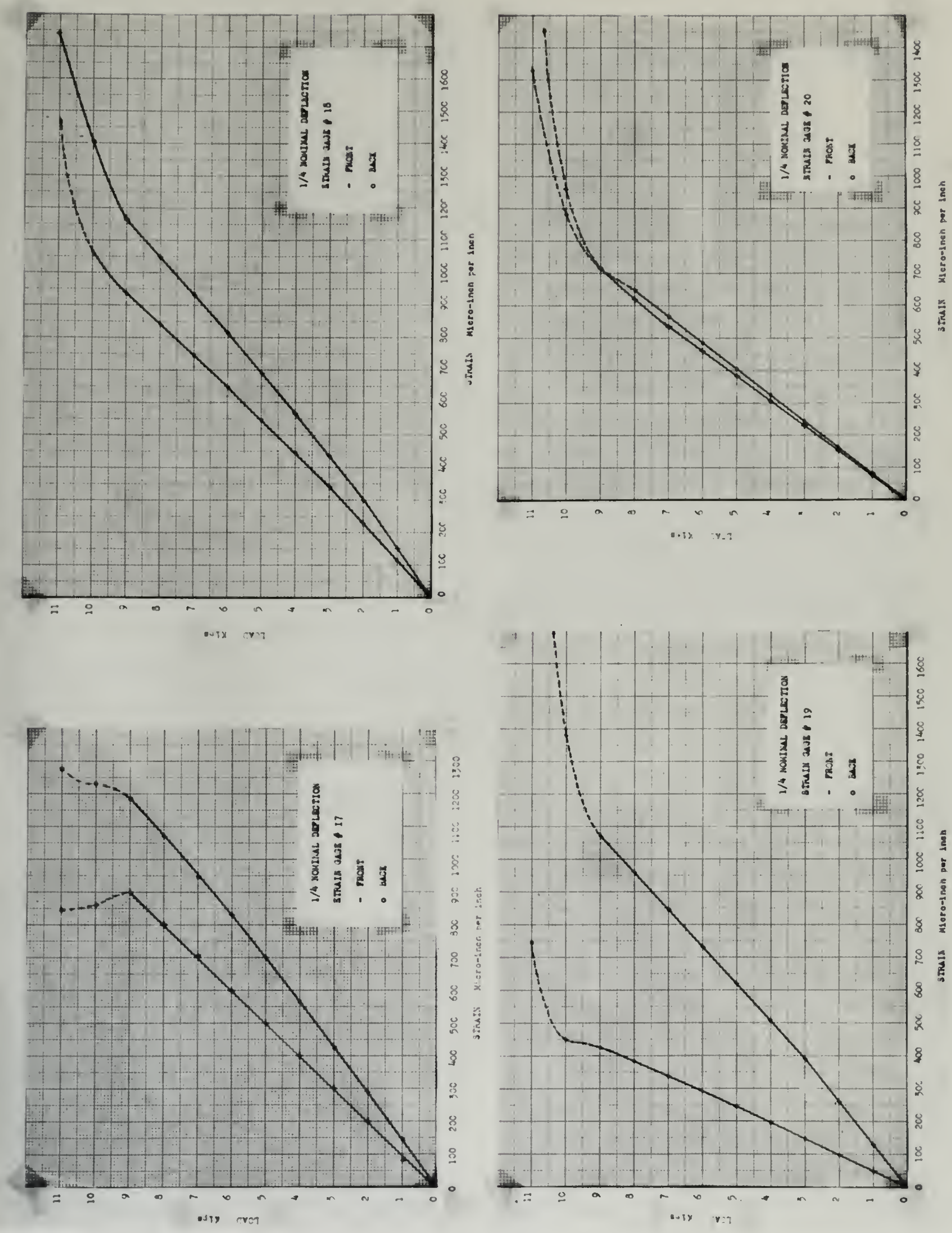
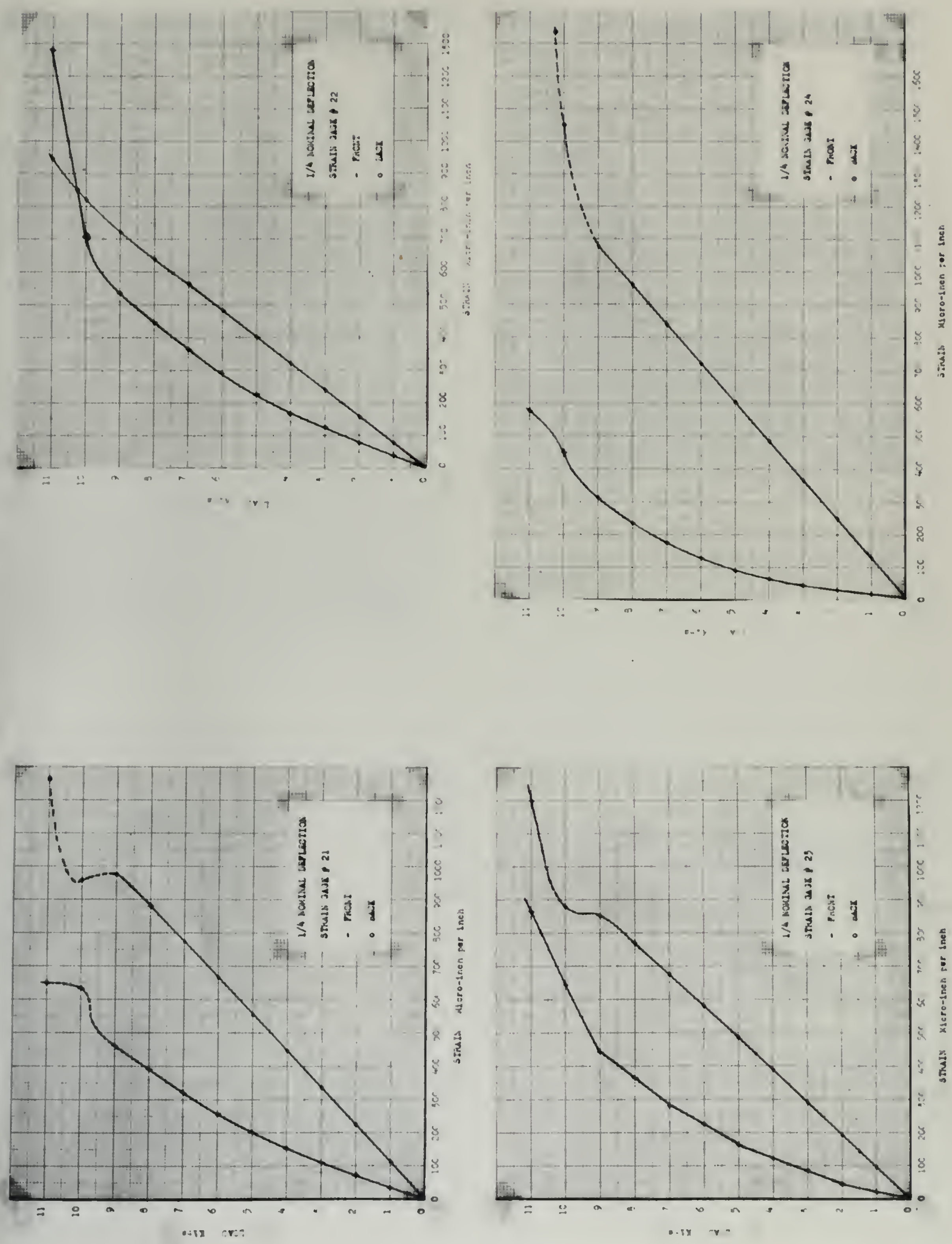

1/4 NOMINAL DEFLECTION
STRAIN GAGE # 18
- FRONT
o BACK
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 20
- FRONT
o BACK
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 17
- FRONT
o BACK
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 19
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XLI



1/4 NOMINAL DEFLECTION
STRAIN GAGE # 22
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 24
STRAIN Micro-inch per inch
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 21
STRAIN Micro-inch per inch
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 23
STRAIN Micro-inch per inch

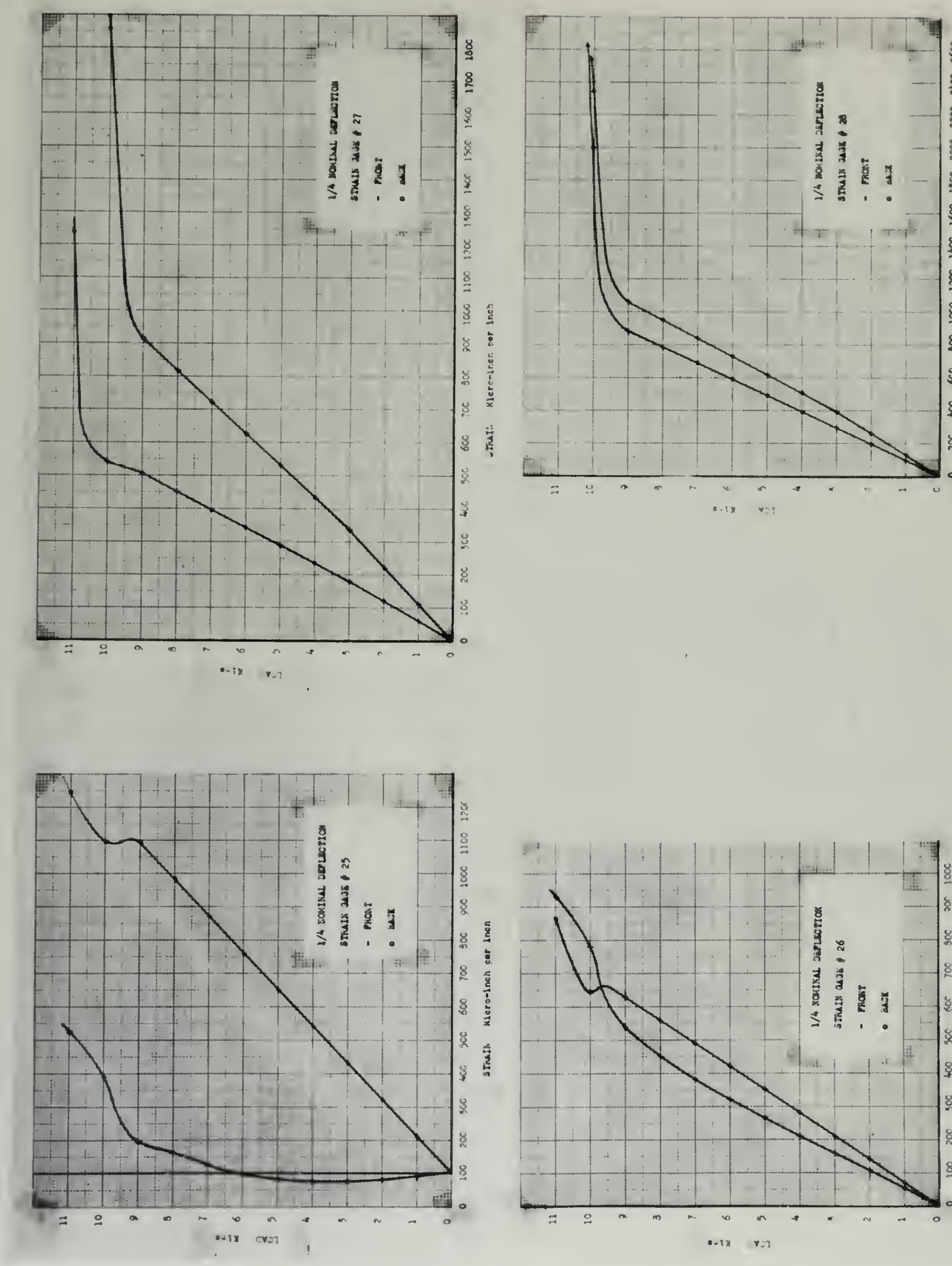
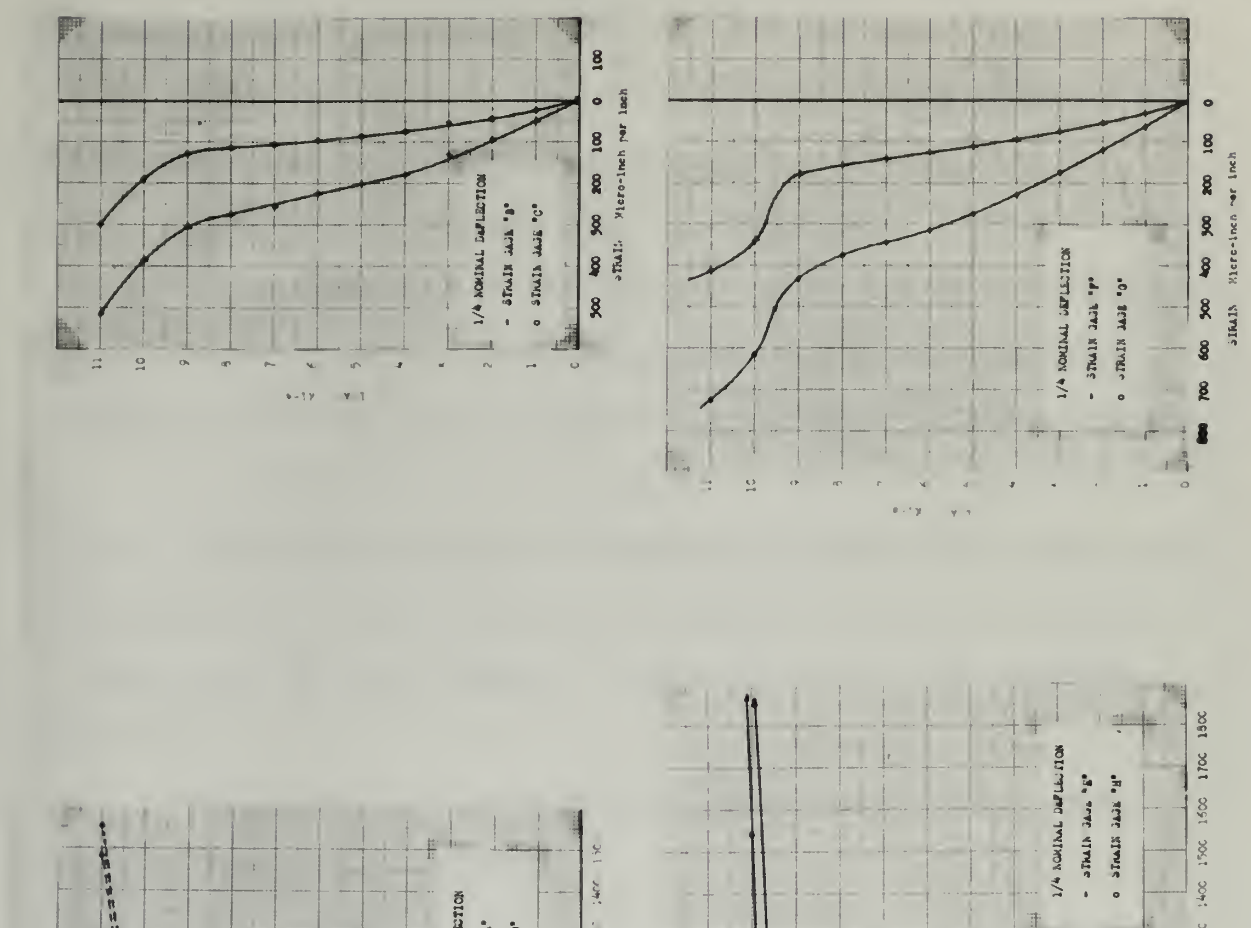

1/4 NOMINAL DEFLECTION
STRAIN GAGE # 27
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 28
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 25
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips
1/4 NOMINAL DEFLECTION
STRAIN GAGE # 26
- FRONT
o BACK
STRAIN Micro-inch per inch
LOAD Kips

FIGURE XLIII



The maximum value of the strain in the front face at each level of load was obtained by taking the arithmetical mean of the strain values indicated by gages 7 front and 11 front.

The minimum value of the strain on the back face at each level of load was computed by taking the arithmetical mean average of the strain values of gages 8 back, 9 back, and 10 back.

The maximum value of the strain at the mid-depth of the plate at each level of load was calculated by taking the arithmetical mean average of the strain values of gages 4 front, 4 back, 14 front, and 14 back.

The ratios of maximum and minimum to average strain values were plotted against the ratios of average deflection (obtained as indicated in section 2.4) to plate thickness. These curves are shown in Figure LVII.

Table VII in the Appendix C contains the calculation of the values and ratios mentioned above.

2.11 Measured and Calculated Applied Load

The product of the average strain, the cross-sectional area of the plate, and the modulus of elasticity equals the magnitude of the load supported by the plate.

From the curves of the strain distribution in the stiffeners, shown in Figure LVI, the arithmetical mean average strain in the two stiffeners of each plate was obtained. Multiplying this value by the product of the cross-sectional area of the stiffeners and the modulus of elasticity gives the magnitude of the load supported by the stiffeners.

The maximum value of the strain in the front face at each level of load was obtained by taking the arithmetical mean of the strain values indicated by gages 7 front and 11 front.

The minimum value of the strain on the back face at each level of load was computed by taking the arithmetical mean average of the strain values of gages 8 back, 9 back, and 10 back.

The maximum value of the strain at the mid-depth of the plate at each level of load was calculated by taking the arithmetical mean average of the strain values of gages 4 front, 4 back, 14 front, and 14 back.

The ratios of maximum and minimum to average strain values were plotted against the ratios of average deflection (obtained as indicated in section 2.4) to plate thickness. These curves are shown in Figure LVII.

Table VII in the Appendix C contains the calculation of the values and ratios mentioned above.

2.11 Measured and Calculated Applied Load

The product of the average strain, the cross-sectional area of the plate, and the modulus of elasticity equals the magnitude of the load supported by the plate.

From the curves of the strain distribution in the stiffeners, shown in Figure LVI, the arithmetical mean average strain in the two stiffeners of each plate was obtained. Multiplying this value by the product of the cross-sectional area of the stiffeners and the modulus of elasticity gives the magnitude of the load supported by the stiffeners.

The sum of the load on the plate and the load on the stiffeners should be equal to the applied load. This comparison was made for a load of 60,000 pounds, assuming a modulus of elasticity of the material of 29,000,000 pounds per square inch, and the difference between the applied load and the calculated load was

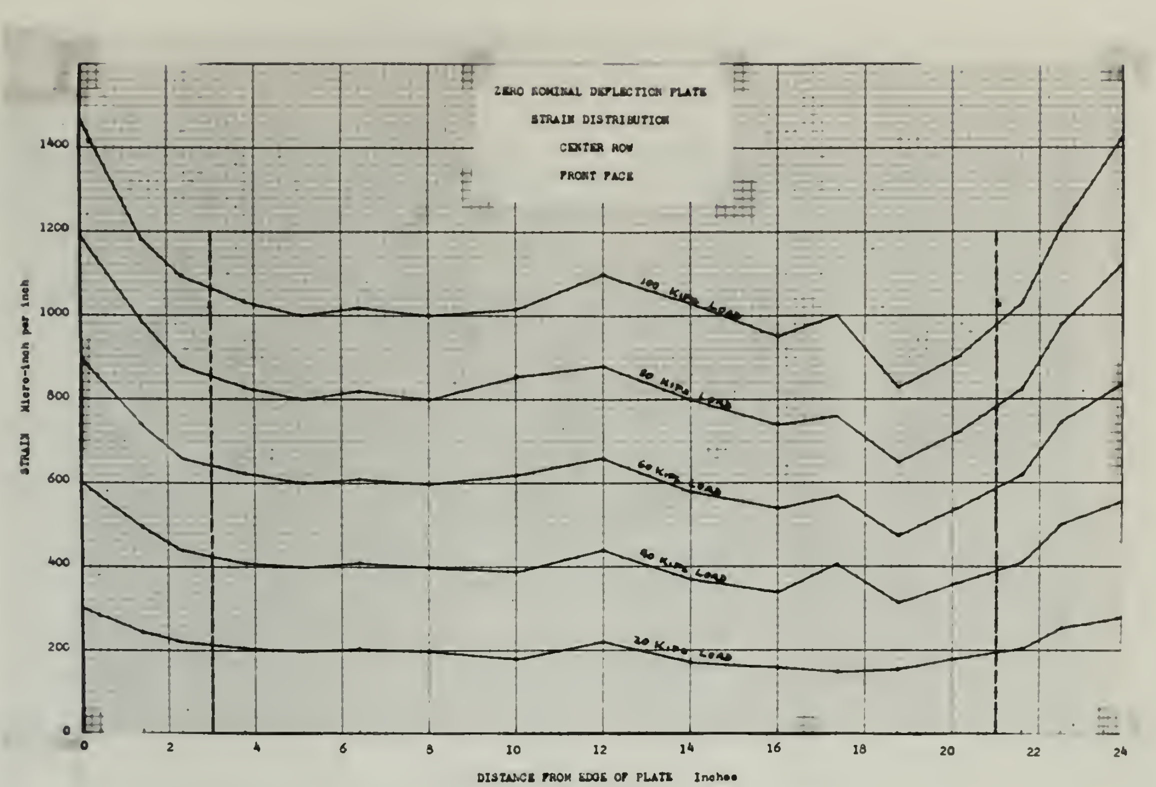
- 800 pounds or -1.33% for the plate of zero nominal deflection
5400 pounds or 9 % for the plate of 1/8" nominal deflection
4000 pounds or 6.7 % for the plate of 3/16" nominal deflection
-1100 pounds or -1.8 % for the plate of 1/4" nominal deflection.

The differences were considered small and within the accuracy of the measurements. The calculation is shown in Appendix D.

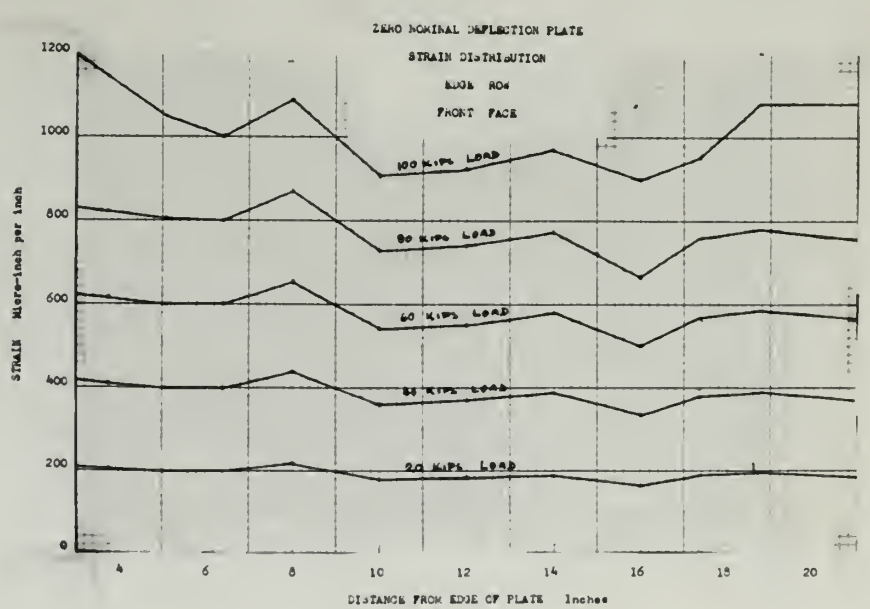
III RESULTS

The results of this investigation are shown in Figures XLIV through LVII.

FIGURE XLIV

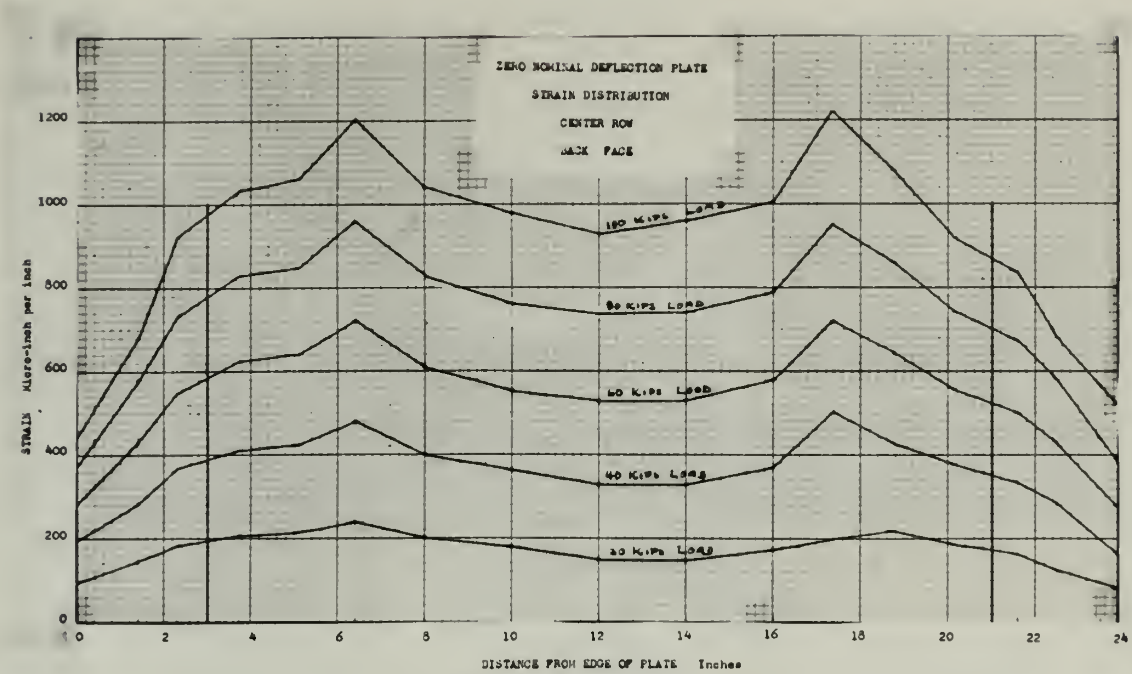


ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
FRONT FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches



ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
FRONT FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE XLV


ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
BACK FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
0
200
400
600
800
1000
1200
0
2
4
6
8
10
12
14
16
18
20
22
24
DISTANCE FROM EDGE OF PLATE Inches

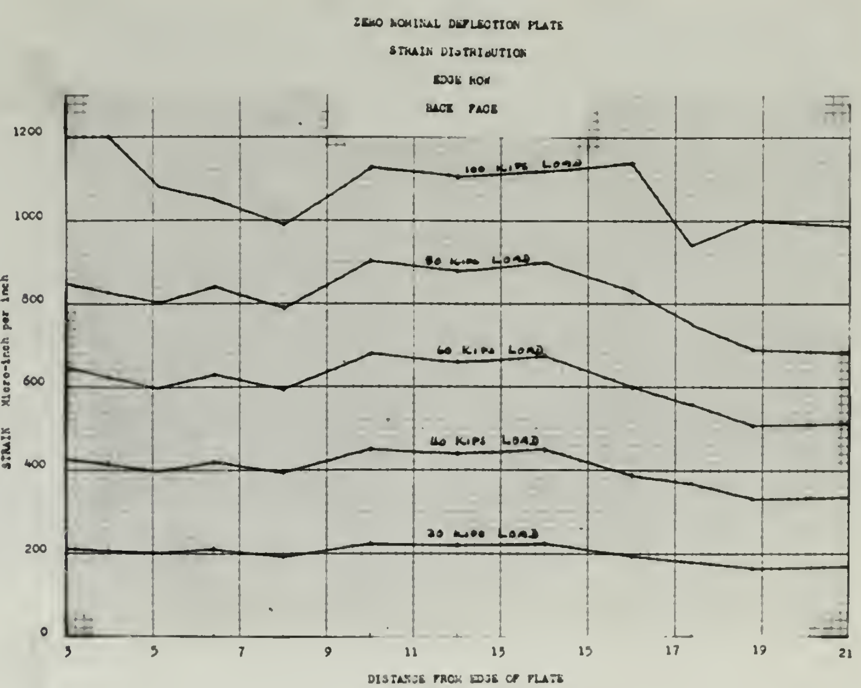
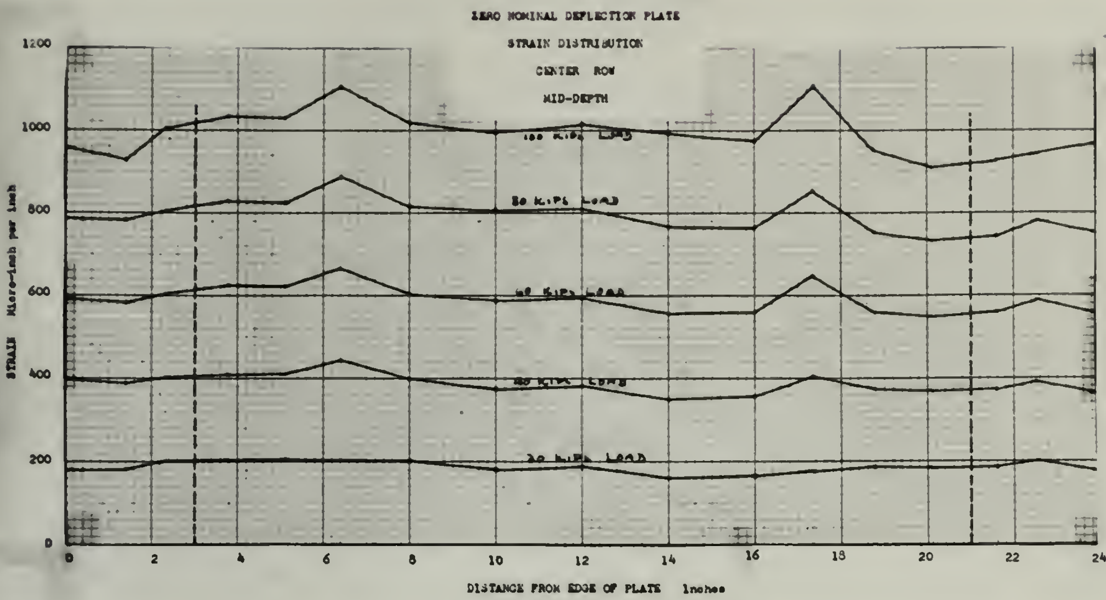

ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
BACK FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
0
200
400
600
800
1000
1200
3
5
7
9
11
13
15
17
19
21
DISTANCE FROM EDGE OF PLATE

FIGURE XLVI


ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
MID-DEPTH
100 Kips Load
80 Kips Load
60 Kips Load
40 Kips Load
20 Kips Load
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE inches

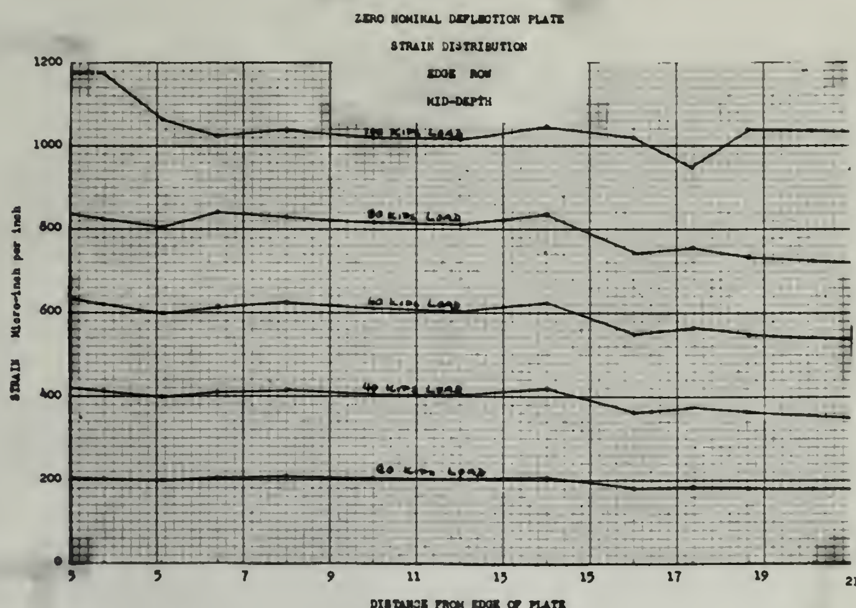
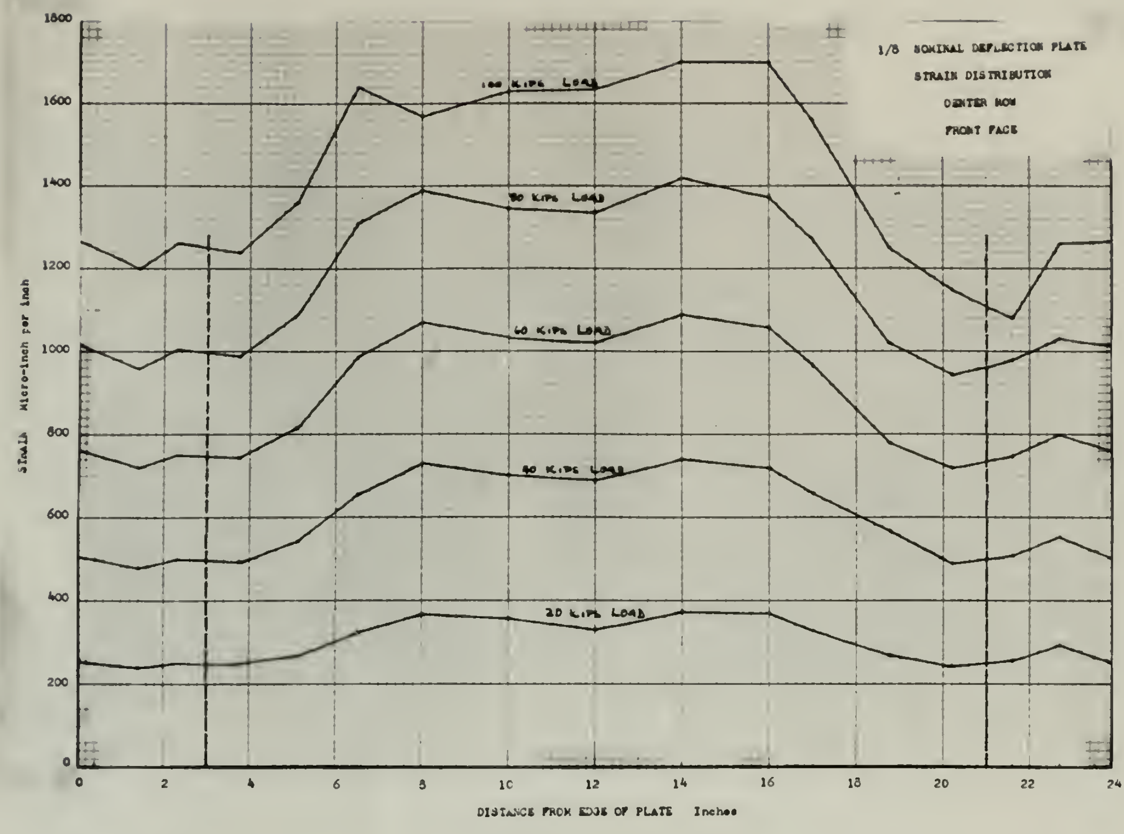

ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
MID-DEPTH
100 Kips Load
80 Kips Load
60 Kips Load
40 Kips Load
20 Kips Load
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE

FIGURE XLVII



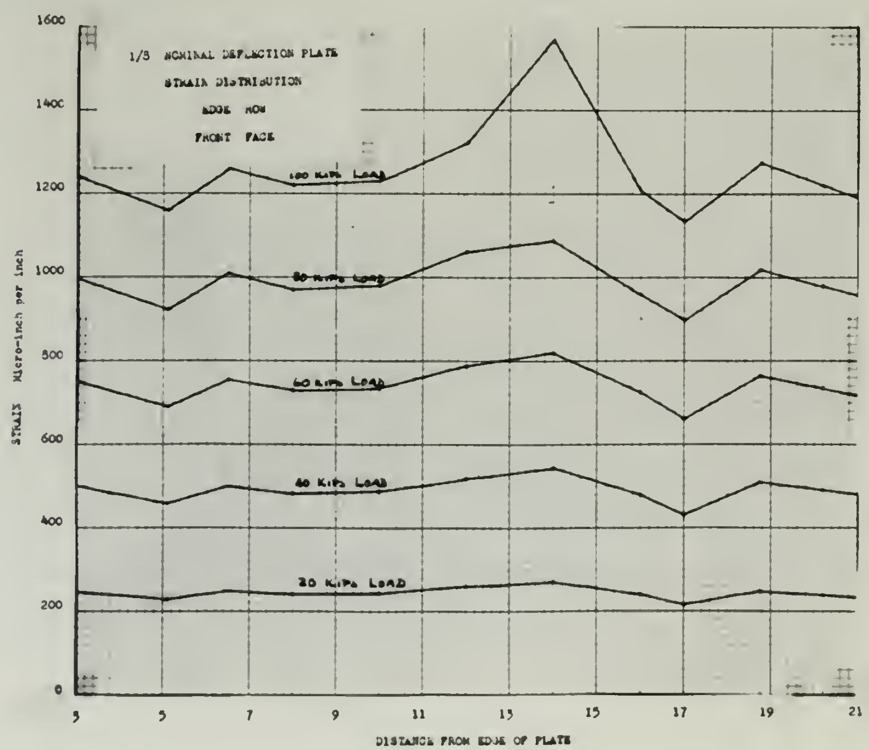
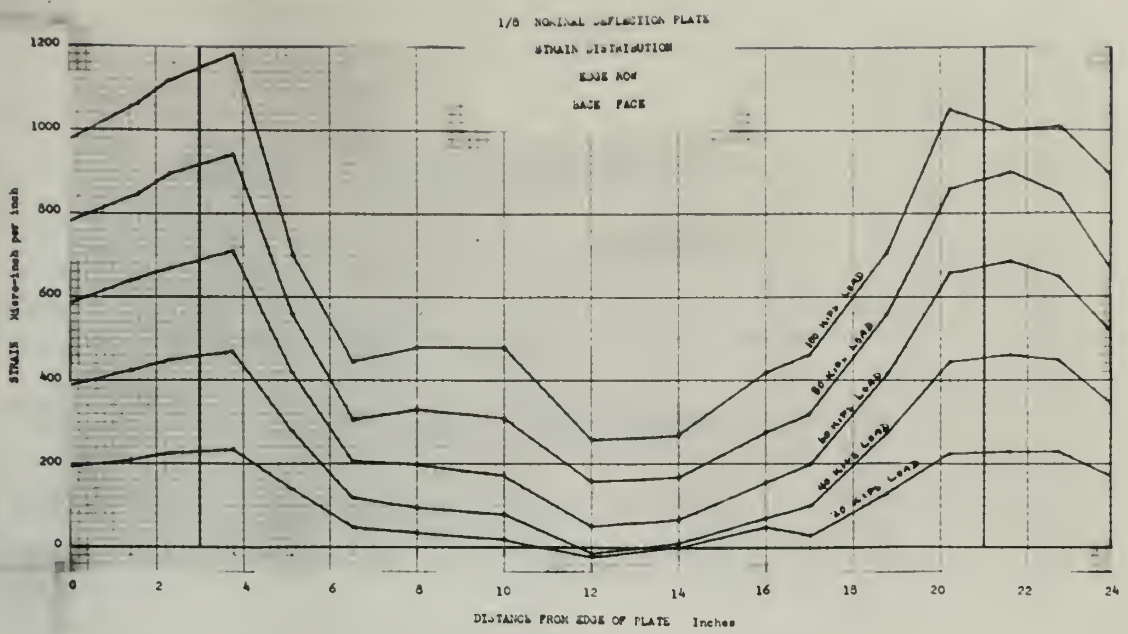


FIGURE XLVIII



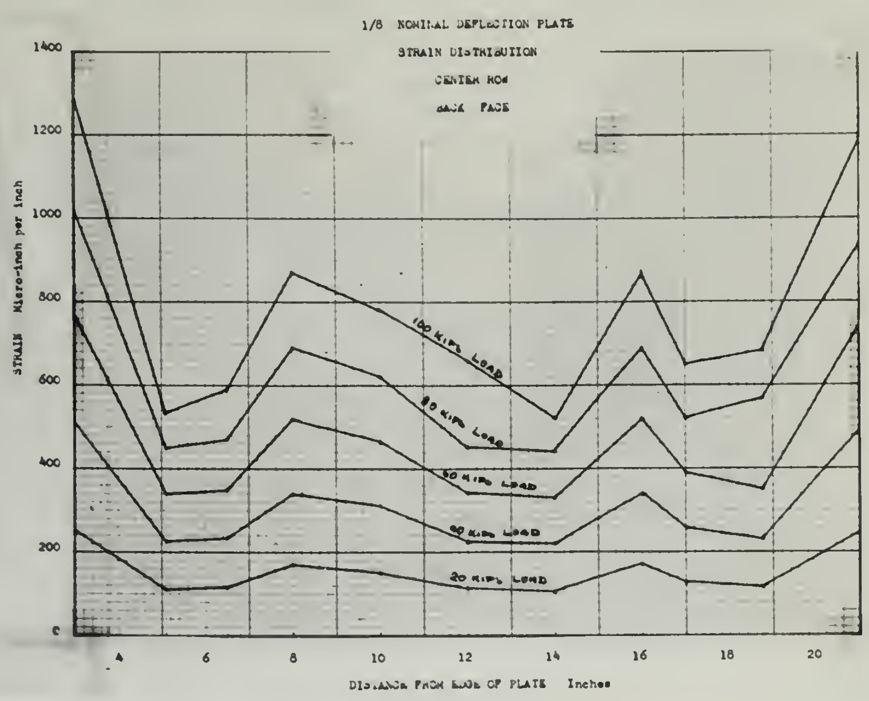
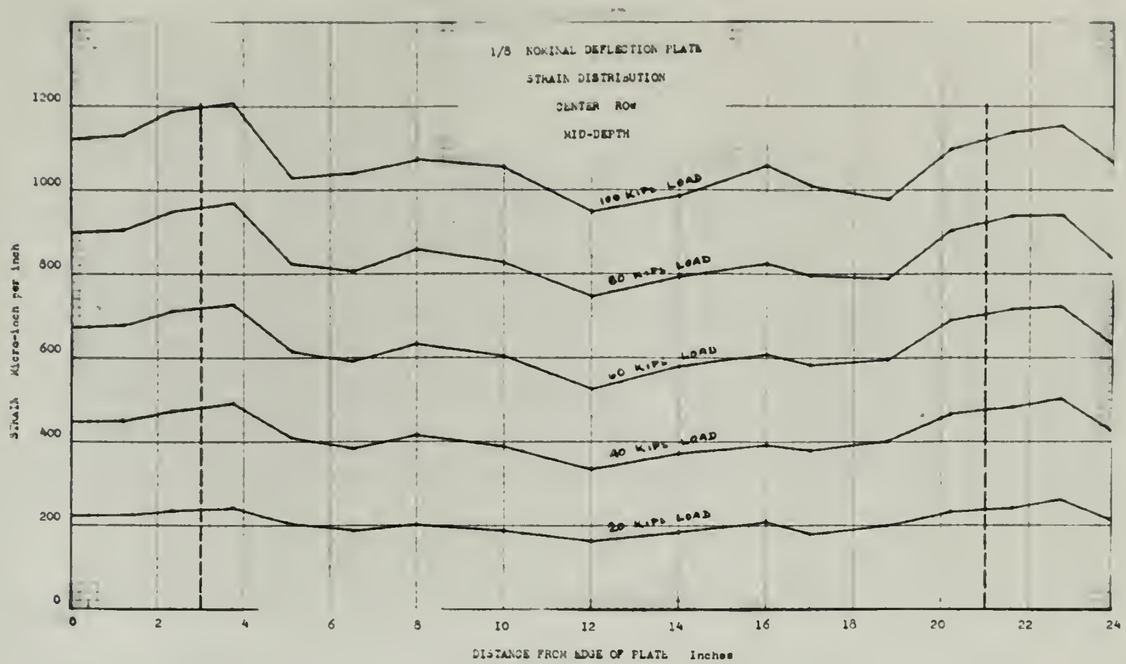


FIGURE XLIX


1/8 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

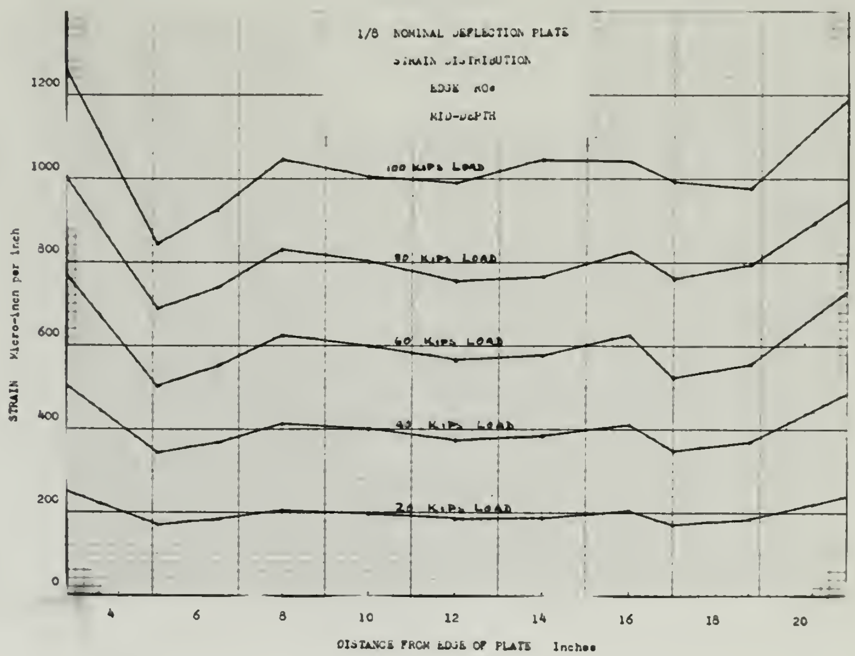
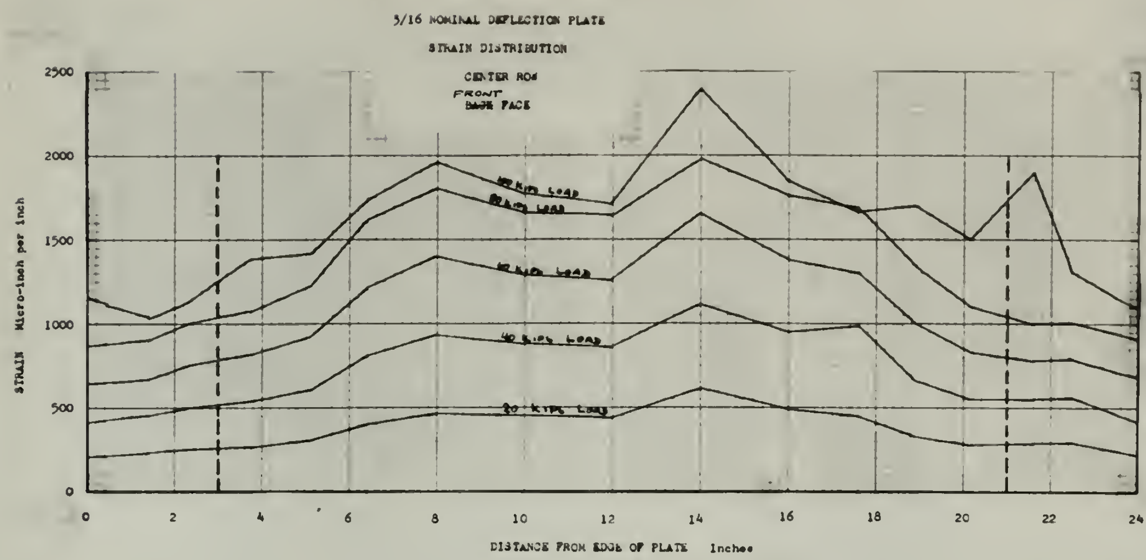

1/8 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE L


5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
FRONT
~~BACK~~ FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

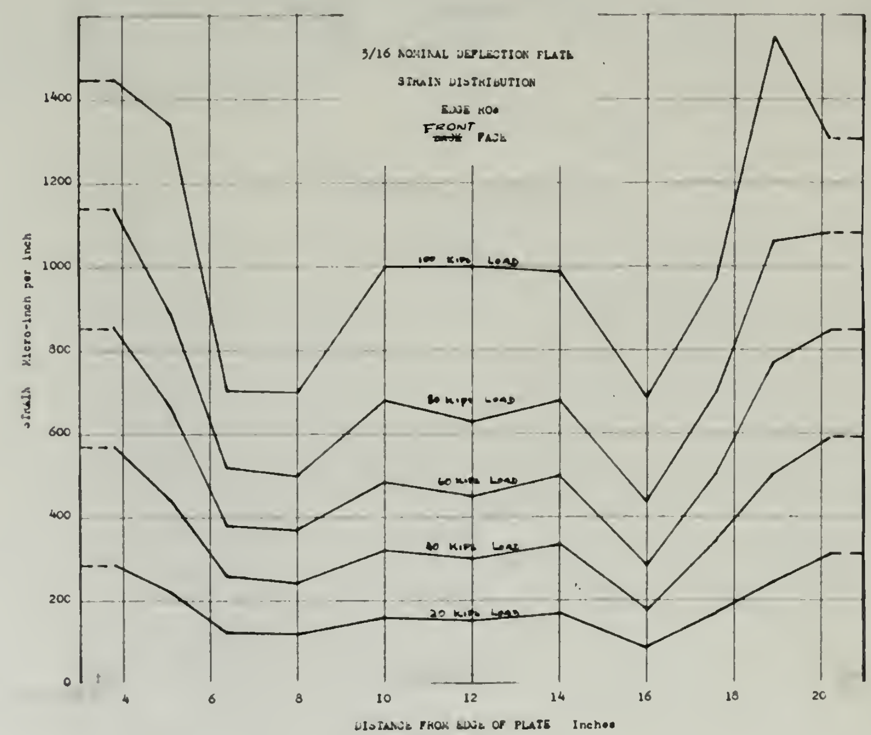
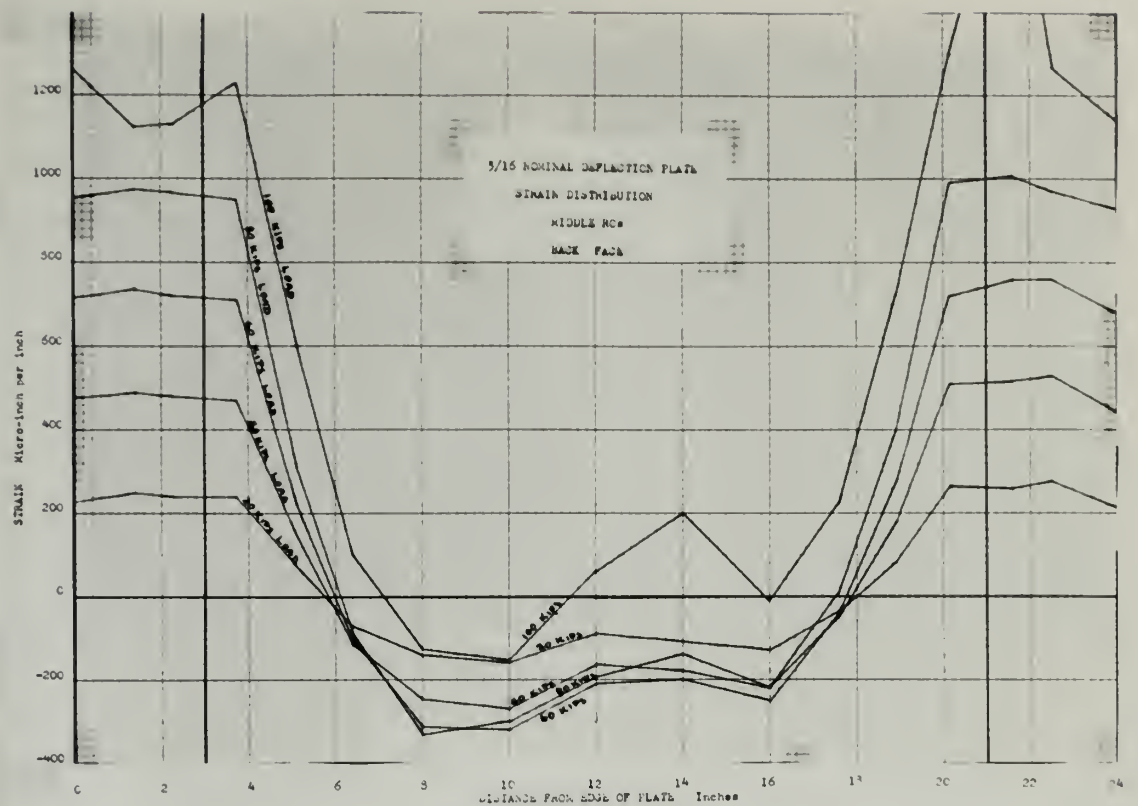
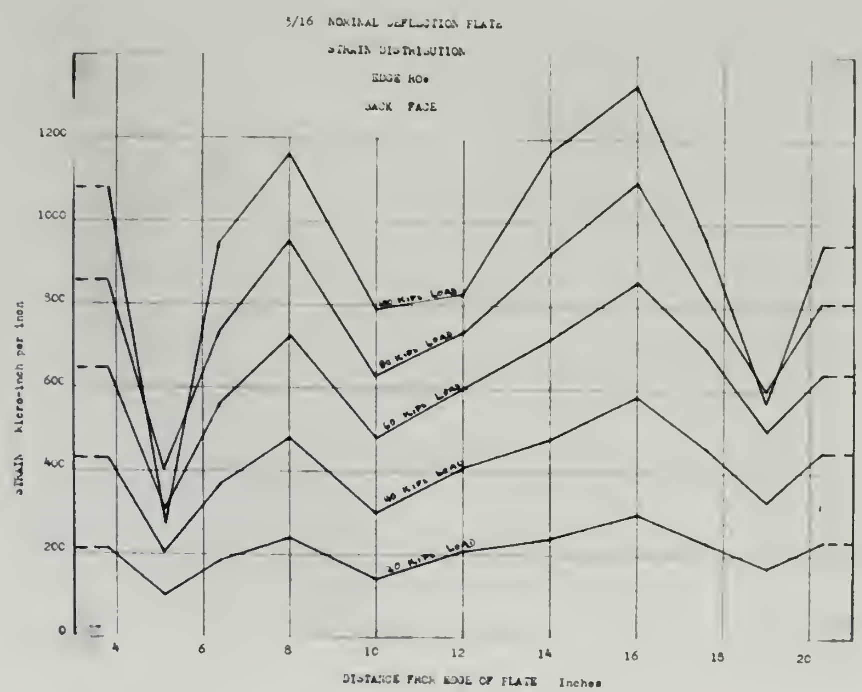

5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
FRONT
~~BACK~~ FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE LI

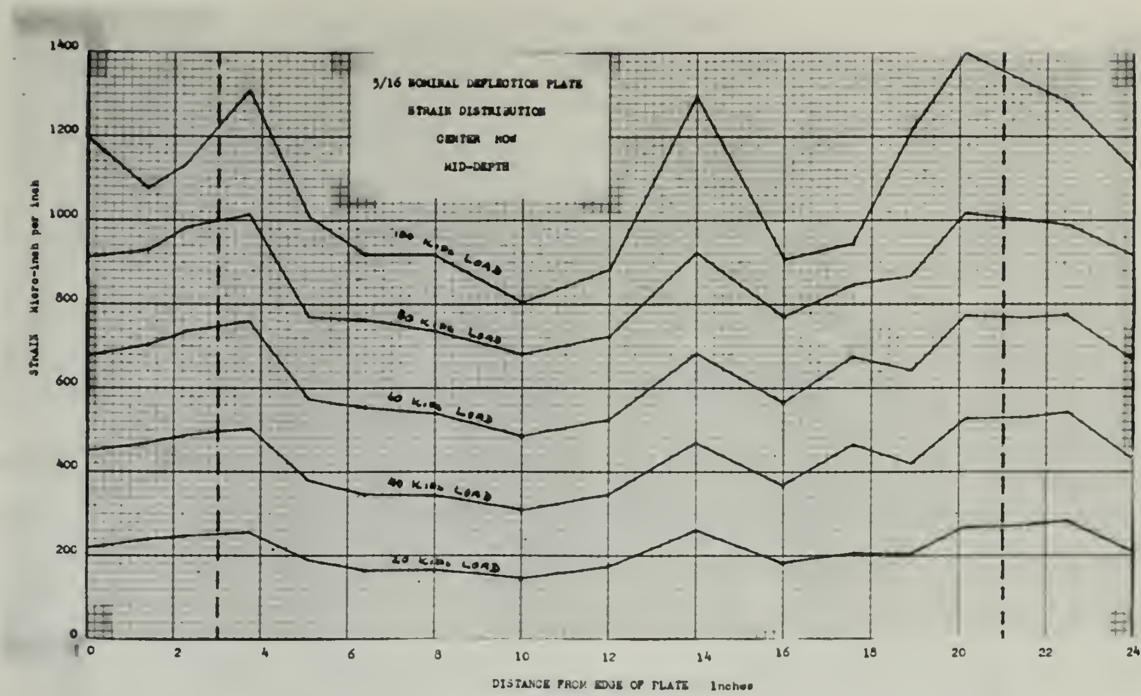


5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
MIDDLE ROW
BACK FACE
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

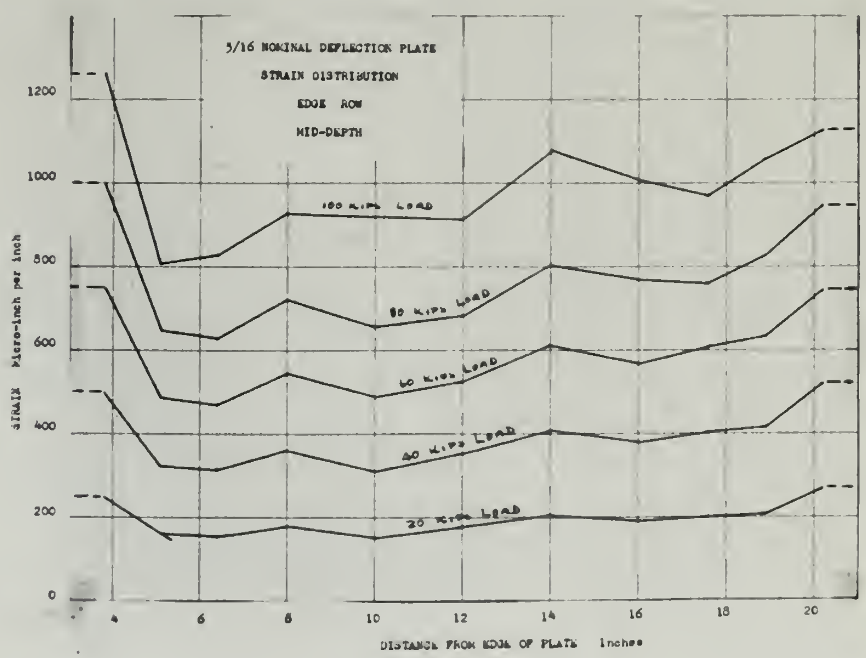


5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
BACK FACE
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE LII

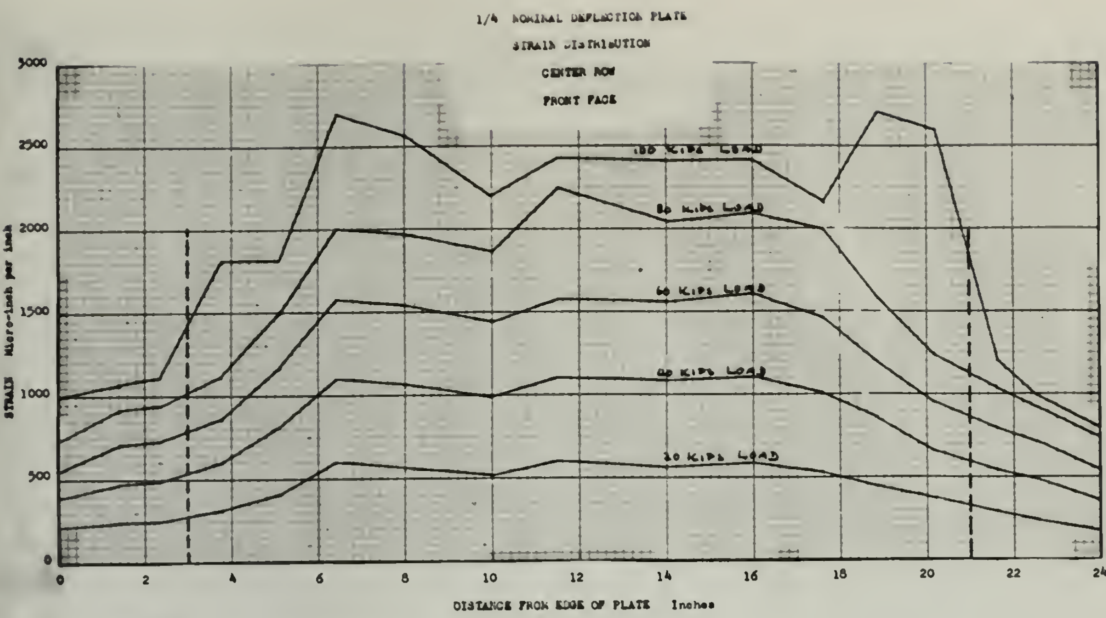


5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches



5/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE LIII


1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
FRONT FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

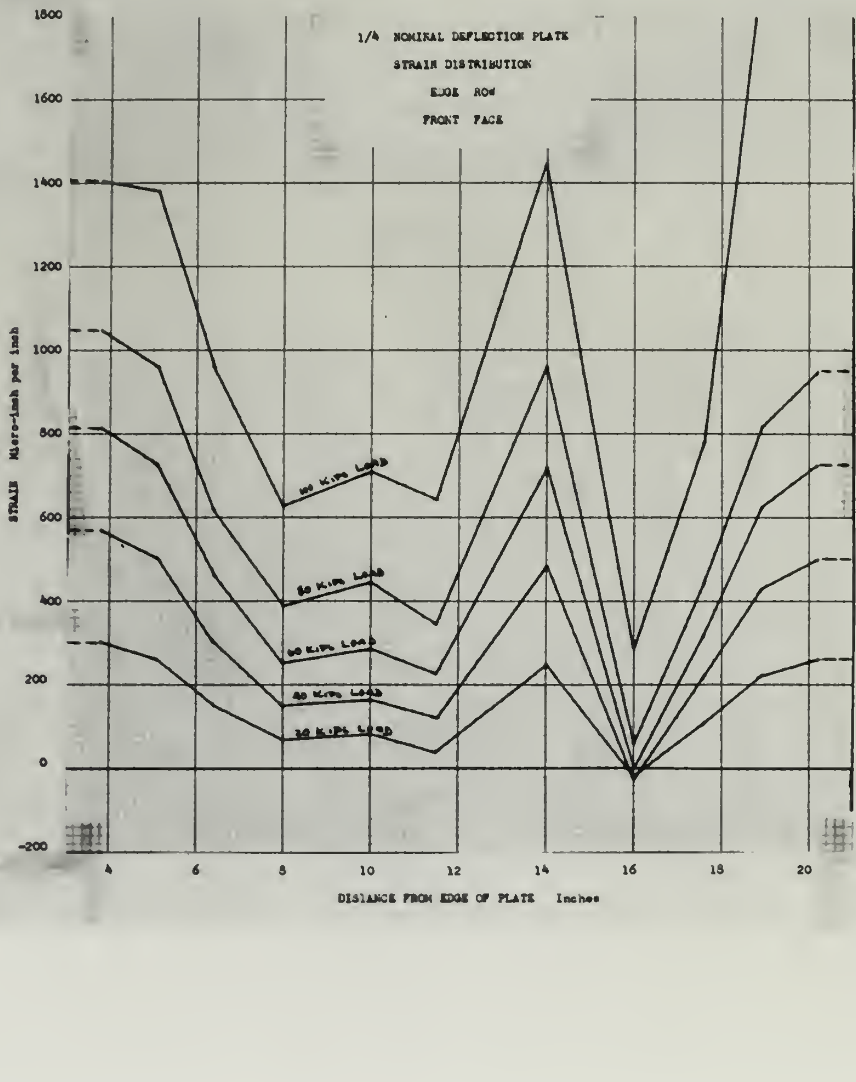
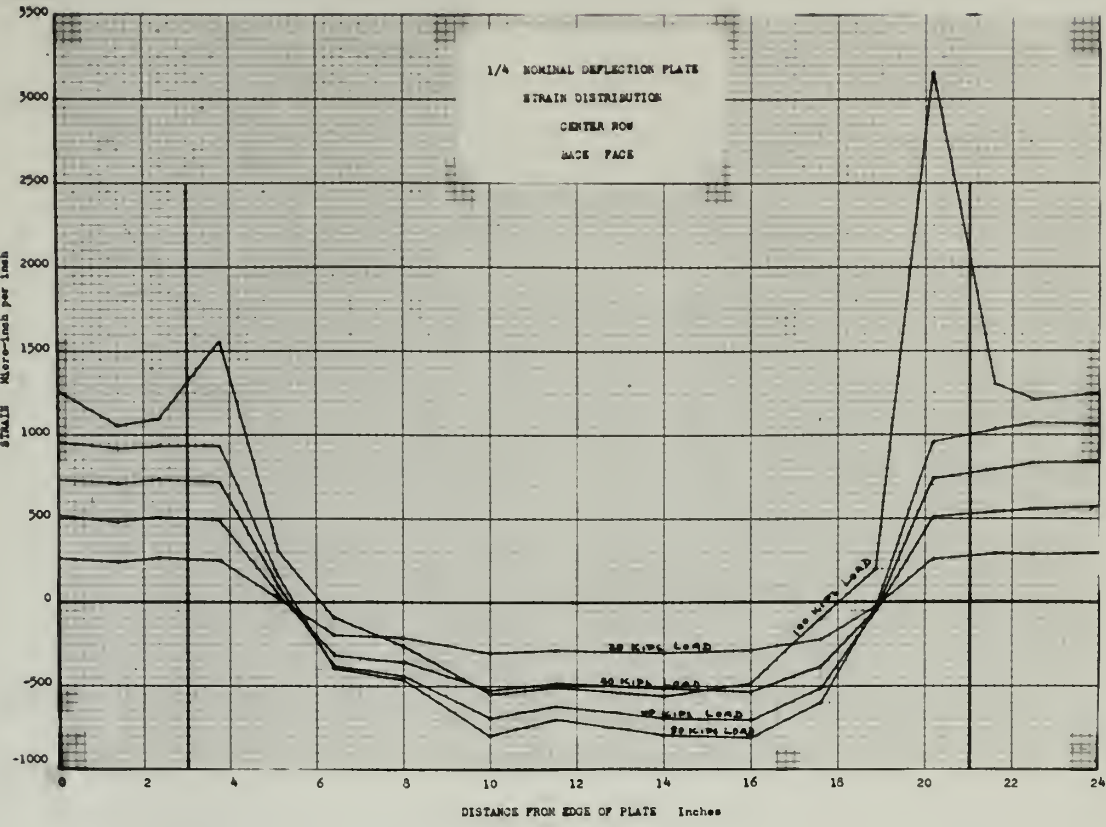

1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
FRONT FACE
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE LIV


1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
BACK FACE
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches
100 KIPS LOAD
20 KIPS LOAD
40 KIPS LOAD
60 KIPS LOAD
80 KIPS LOAD

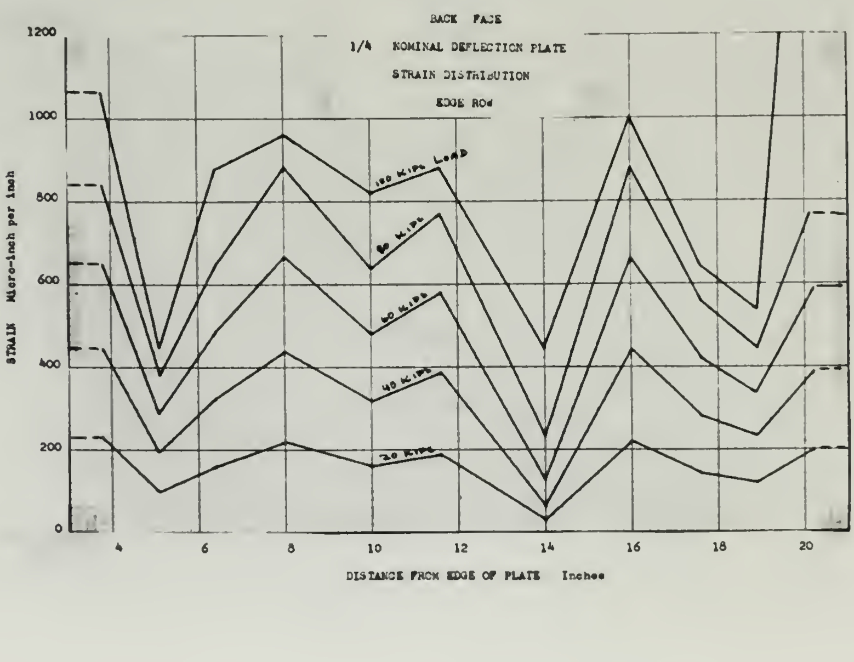
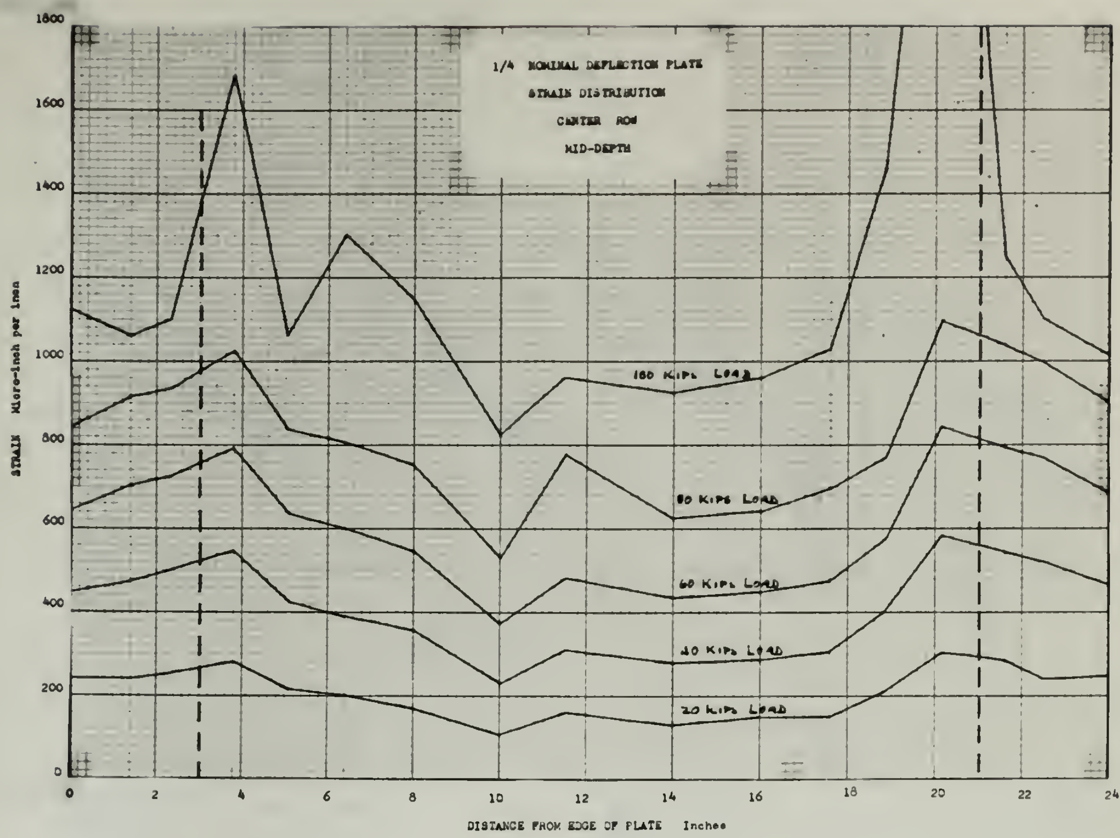
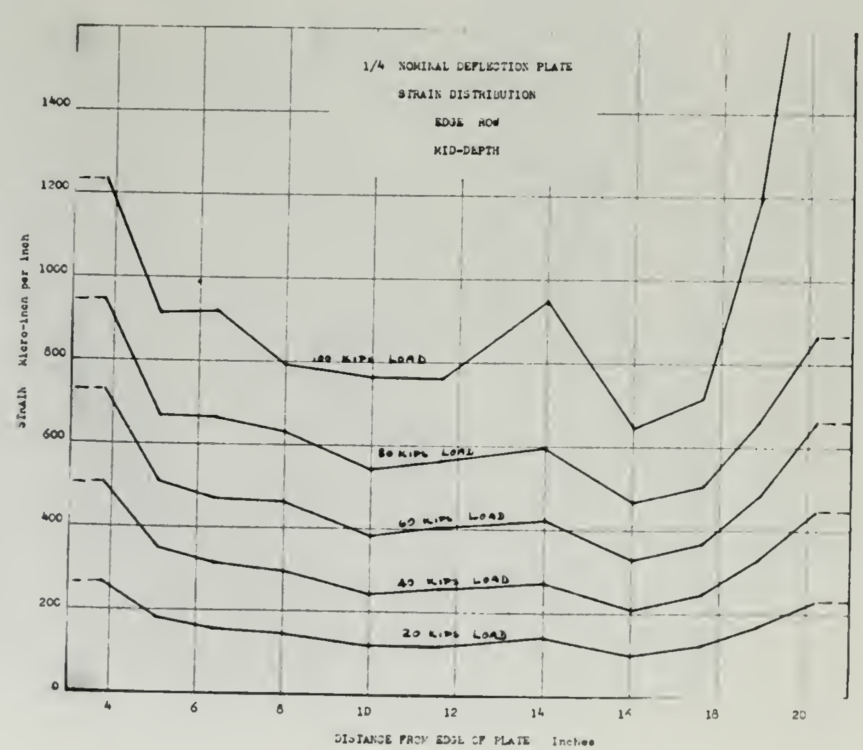

BACK FACE
1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches
100 KIPS LOAD
80 KIPS
60 KIPS
40 KIPS
20 KIPS

FIGURE LV

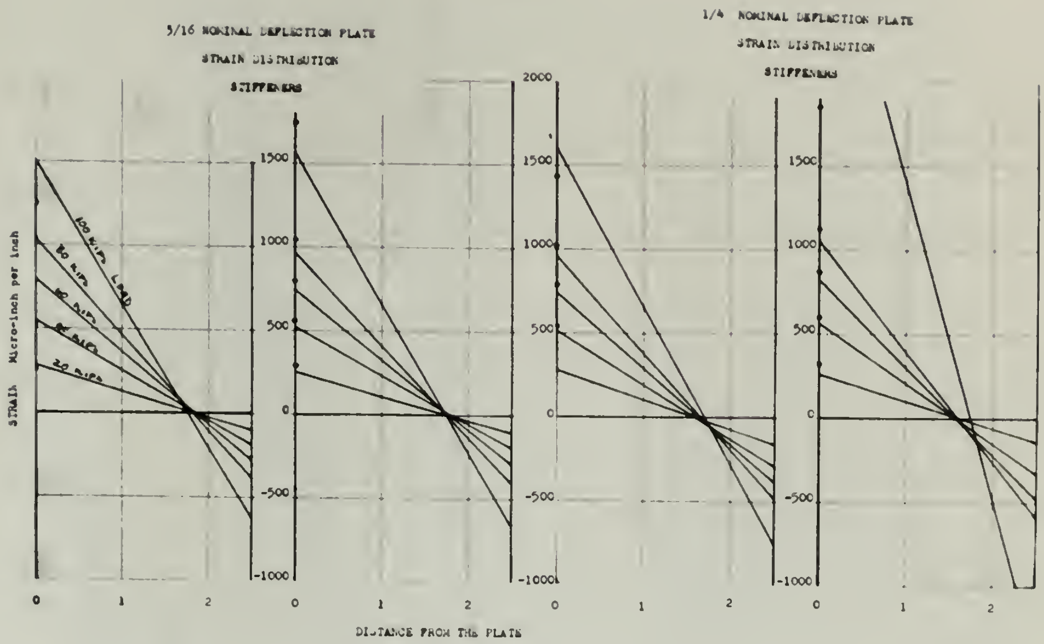


1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
CENTER ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

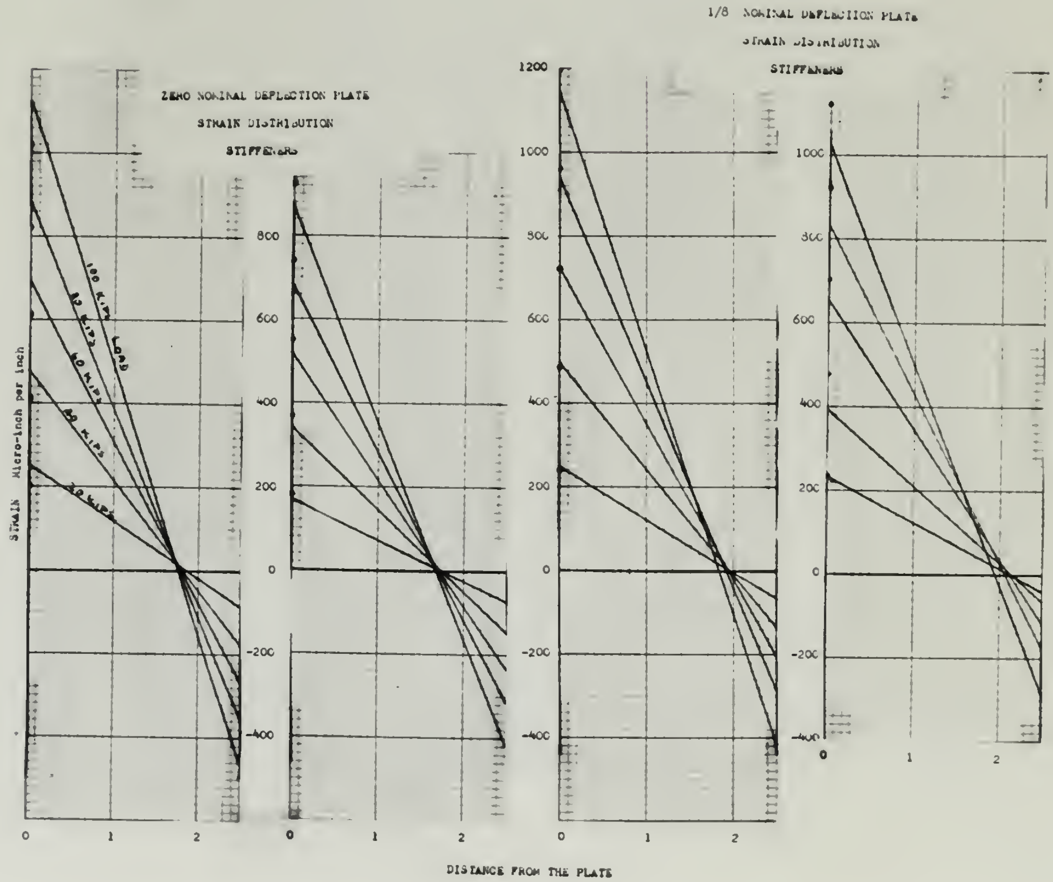


1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
EDGE ROW
MID-DEPTH
100 KIPS LOAD
80 KIPS LOAD
60 KIPS LOAD
40 KIPS LOAD
20 KIPS LOAD
STRAIN Micro-inch per inch
DISTANCE FROM EDGE OF PLATE Inches

FIGURE LVI

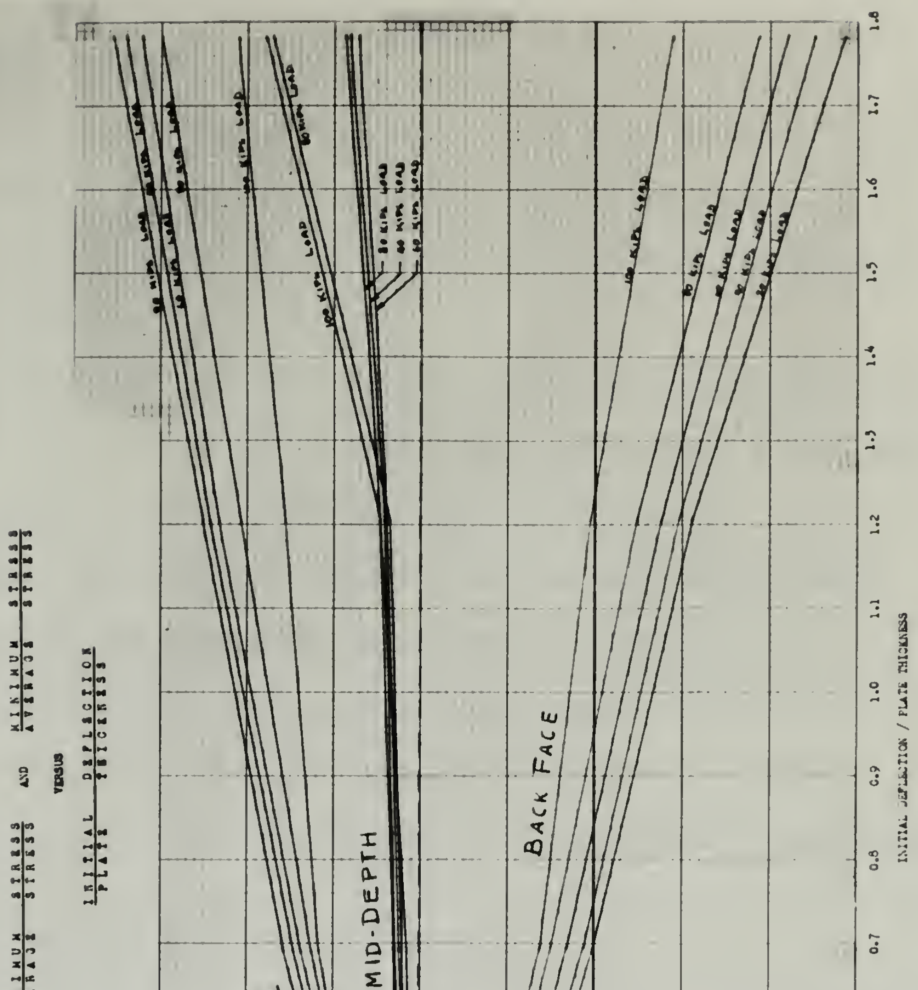


3/16 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
STIFFENERS
1/4 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
STIFFENERS
100 KIPS LOAD
80 KIPS
60 KIPS
40 KIPS
20 KIPS
STRAIN Micro-inch per inch
DISTANCE FROM THE PLATE



ZERO NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
STIFFENERS
1/8 NOMINAL DEFLECTION PLATE
STRAIN DISTRIBUTION
STIFFENERS
100 KIPS LOAD
80 KIPS
60 KIPS
40 KIPS
20 KIPS
STRAIN Micro-inch per inch
DISTANCE FROM THE PLATE

FIGURE LVII


MAXIMUM STRESS / AVERAGE STRESS AND MINIMUM STRESS / AVERAGE STRESS
VERSUS
INITIAL DEFLECTION / PLATE THICKNESS
FRONT FACE
MID-DEPTH
BACK FACE
100 KIPS LOAD
80 KIPS LOAD
INITIAL DEFLECTION / PLATE THICKNESS
MAXIMUM STRESS / AVERAGE STRESS
MINIMUM STRESS / AVERAGE STRESS

IV DISCUSSION OF THE RESULTS

4.1 Strain-Load Curves

The strain-load curves (Figures XV through XLIII) indicated that the strain-load relation is not linear for the structure tested. The departure from linear performance increases with the increase of initial deflection.

In the 3/16" nominal deflection plate and in the 1/4" nominal deflection plate there were measured strains greater than 2,400 micro-inch per inch for a load of 100 kips, particularly on the front face near the center of the plate. These strains indicate stress values greater than the yield stress of mild steel.

Therefore, it was considered that a strain distribution analysis would provide a more representative indication of what is actually taking place under load than an estimated stress distribution.

4.2 Strains Near the Transverse Stiffeners

The strain gages used to obtain the strain distribution were oriented in the direction of the principal strains indicated by the stress-coat analysis, as explained in section 2.5.

The crack pattern of the stress-coat started to form at a load of about 60 kips, and was completed by the time the load had increased to 80 kips.

It is believed that the orientation of the principal strains changed with the variation of the load because the magnitude of the deflection of the panel probably changed with the load. Therefore, the

IV DISCUSSION OF THE RESULTS

4.1 Strain-Load Curves

The strain-load curves (Figures IV through XLIII) indicated that the strain-load relation is not linear for the structure tested. The departure from linear performance increases with the increase of initial deflection.

In the 3/16" nominal deflection plate and in the 1/4" nominal deflection plate there were measured strains greater than 2,400 micro-inch per inch for a load of 100 kips, particularly on the front face near the center of the plate. These strains indicate stress values greater than the yield stress of mild steel.

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It is believed that the orientation of the principal strains changed with the variation of the load because the magnitude of the deflection of the panel probably changed with the load. Therefore, the

observations made along the row of strain gages near the stiffeners have a limited significance. Future reference herein to strains should be construed to mean strains measured along the transverse centerline. It should be realized that the strains measured in the row of strain gages near the transverse stiffeners were always lower in value than the maximum strain measured along the transverse centerline even at the loads of 60 to 80 kips; therefore, there is no loss of generality because it is desired to relate a maximum stress to deflection only.

4.3 Strains at the Transverse Centerline of the Panel

The crack pattern of the stress coat for the four plates at the transverse centerline of the panel (Figures IX through XII) had an orientation parallel to the transverse stiffeners, indicating that the orientation of the principal strains at the transverse centerline of the panel did not change with the initial deflection of the plate, and that the orientation of the principal strains was parallel to the longitudinal axis of the specimen.

By symmetry, the direction of the principal strains should be parallel to the longitudinal axis of the specimen.

Therefore, the strains measured with the strain gages at the transverse centerline of the panel, which were installed with their axes oriented parallel to the longitudinal axis of the specimen, are actually the principal strains.

4.4 Strain Distribution in the Unstiffened Side of the Plate

The curves of strain distribution on the unstiffened side of

the plate (Figures XLIV, XLVII, L, and LIII) indicated two maximum strain values at about the quarter points of the transverse centerline of the panel.

4.5 Strain Distribution in the Stiffened Side of the Plate

The curves of strain distribution in the stiffened side of the plate (Figures XLV, XLVIII, LI, and LIV) indicated minimum strain values at about the center of the panel.

4.6 Strain Distribution in the Mid-Depth of the Plate

The curves of strain distribution at the mid-depth of the plate (Figures XLVI, XLIX, LII, and LV) indicated two maximum strain values at the transverse centerline of the panel near to the stiffeners and a minimum strain value at the center of the panel.

4.7 Strain Distribution in the Stiffeners

The strains measured in the stiffeners were always smaller than the average strain in the plate. This indicated that the stiffeners were not sharing the load with the plate, which condition resulted from the load not being applied in line with the position of the neutral axis of the test section. For this reason, a shear load between the plate and the stiffeners existed. The stiffeners were loaded in tension at the bottom edge which caused a bending moment effect on the stiffeners, as can be observed in Figure LVI. The tendency of the shear to produce a compressive effect on the plate reduced the tensile strain in the plate near the stiffeners. Therefore it is believed that the strains in the portion of the plate adjacent to the stiffeners would have a higher value than the measured one if the stiffeners were sharing properly the applied load.

the plate (Figures XLIV, XLVII, L, and LIII) indicated two maximum strain values at about the quarter points of the transverse centerline of the panel.

4.5 Strain Distribution in the Stiffened Side of the Plate

The curves of strain distribution in the stiffened side of the plate (Figures XLV, XLVIII, LI, and LIV) indicated minimum strain values at about the center of the panel.

4.6 Strain Distribution in the Mid-Depth of the Plate

The curves of strain distribution at the mid-depth of the plate (Figures XLVI, XLIX, LII, and LV) indicated two maximum strain values at the transverse centerline of the panel near to the stiffeners and a minimum strain value at the center of the panel.

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The strains measured in the stiffeners were always smaller than the average strain in the plate. This indicated that the stiffeners were not sharing the load with the plate, which condition resulted from the load not being applied in line with the position of the neutral axis of the test section. For this reason, a shear load between the plate and the stiffeners existed. The stiffeners were loaded in tension at the bottom edge which caused a bending moment effect on the stiffeners, as can be observed in Figure LVI. The tendency of the shear to produce a compression effect on the plate reduced the ~~tot~~ tensile strain in the plate near the stiffeners. Therefore it is believed that the strain in the portion of the plate adjacent to the stiffeners would have a higher value than the measured one if the stiffeners were sharing properly the applied load.

To reduce the shearing force between the plate and the stiffeners the specimens would have to be redesigned. By using stiffeners on both sides of the plate and very stiff members welded at the ends of the test section, an even distribution of load between the stiffeners and the plate would be obtained.

4.8 Strain-Deflection Relationship

Figure LVII shows that the ratios of the maximum stress in the unstiffened side of the plate to the average stress in the plate, of the minimum stress in the stiffened side of the plate to the average stress in the plate, and of the maximum stress in the mid-depth of the plate to the average stress in the plate varied almost linearly with the ratios of the initial deflection to the plate thickness within the elastic region of the material.

The values of the stress ratios mentioned above approach unity as the applied load increases within the elastic region of the material. This effect may be explained if it is realized that the deflection of the panel decreases as the applied load increases.

It should be mentioned that for a load of 80 kips in the 3/16" and in the 1/4" nominal deflection plates and for a load of 100 kips in all of the plates, the stresses exceeded the yield point of the material, as can be observed in the load-strain curves (Figures XV through XLIII). For this reason, the stress ratio curves of Figure LVII actually indicate for all values of the deflection-thickness ratio and for the load of 80 kips for the range deflection-thickness ratios greater than 1.2.

4.9 Section of the Plate Adjacent to the Longitudinal Stiffeners

When the tensile load was applied to the test sections with initial deflection, the maximum stresses in the mid-depth of the plate were produced at the region of the panel adjacent to the longitudinal stiffeners. The material at the center of the panel was initially curved, while the material adjacent to the longitudinal stiffeners was straight; therefore, when the tensile load was applied, the curved fibers were unable to assume a strictly proportionate share of the load.

For an initial-deflection-thickness ratio of 1.5, and a load of 60 kips (8 tons per square inch or 18000 pounds per square inch of average stress in the plate), the claculated ratio of the maximum stress in the mid-depth of the plate at the region adjacent to the longitudinal stiffeners to the average stress in the plate was 1.275. Because the stiffeners did not share the load with the plate, it is believed that this value should be larger. This stress ratio is the stress concentration factor produced by the initial deflection of the panel.

4.10 Center Section of the Panel

When the tensile load was applied on the test sections with initial deflection, the maximum stresses were produced at the center of the panel in the unstiffened side of the plate, and the minimum values of the tensile strain were obtained in the same region in the stiffened side. The center of the panel was by a direct tensile load and by a bending load due to the deflection. The sum of these loads caused a high tensile stress in the concave side of the panel (unstiffened face), and a low tensile stress, some times negative (compressive stress) in the convex side of the plate (stiffened face).

For an initial-deflection-plate thickness ratio of 1.5, and a load of 60 kips (about 8 tons persquare inch or 18000 pounds per square inch of average stress in the plate), the calculated ratio of the maximum stress at the center of the panel in the unstiffened (concave) side of the plate to the average stress in the plate was 2.39. Because the stiffeners did not share the load with the plate, it is believed that the direct tensile stress at the center of the plate would be smaller. However, the bending moment would be larger. The net effect cannot be estimated. The bending moment would be larger, because, if the stiffeners worked fully, the neutral axis of the section (or line of application of the load) would be at a larger distance from the plate at the center of the panel. This calculated stress ratio is the stress concentration factor produced by the initial deflection of the panel.

The stress concentration factor for the unstiffened side of the plate in the central region of the panel is much higher than that for the region of the plate adjacent to the longitudinal stiffeners. Considering the big difference between these two stress concentration factors, it is believed that the stress concentration factor for the central region of the panel would still be the largest one even if the stiffeners properly shared the load.

This stress concentration at the center of the unstiffened side combined with alternation of stresses, is a sufficient cause to produce surface cracks in the plate, which in turn increase the stress concentration causing the complete failure of the plate.

V CONCLUSIONS

5.1 In the unstiffened side of the deflected panels, the maximum stresses are produced at the quarter points of the transverse centerline of the panel.

5.2 In the stiffened side of the deflected panels, the minimum stresses are produced at the center of the panel.

5.3 In the mid-depth of the deflected panels, the maximum stresses are produced in a region adjacent to the longitudinal stiffeners at the transverse centerline of the panel, and the minimum stresses at the center of the panel.

5.4 The ratios of the maximum to the average stress values increase almost linearly with the increase of initial-deflection-plate-thickness ratio within the elastic region of the material. The ratios of the minimums to the average stress values decrease almost linearly with the increase of the initial-deflection-plate-thickness ratio within the elastic region of the material.

5.5 The ratios of the maximums to the average stress values and of the minimums to the average stress values approach unity as the applied load increases within the elastic region of the material.

5.6 The high stress concentrations in the unstiffened side of the plate (concave side) caused by large initial deflections, combined with alternation of stresses, produce surface cracks in the plate.

VI RECOMMENDATIONS

6.1 To reduce the shearing force between the plate and the stiffeners, the specimen should be redesigned using stiffeners on both sides of the plate and very stiff members welded at the ends of the test section so that an even distribution of the load between the stiffeners and the plate would result.

6.2 Investigations should be continued with different aspect ratios until sufficient data is compiled to specify a maximum allowable deflection of panels.

VII APPENDIX

APPENDIX A

TEST DATA

TABLE I
DATA SHEET
INITIAL DEFLECTION READINGS
PLATE OF ZERO NOMINAL DEFLECTION

Station	1	2	3	4	5	6	7	8	9	10	11
1	0	1	1	5	6	9	12	14	13	7	0
2	2	4	5	9	13	15	19	19	17	13	11
3	1	3	3	6	8	9	15	17	16	15	14
4	-5	-0	-2	-1	1	3	8	12	15	17	16
5	-7	-5	-9	-7	-4	-2	0	6	8	12	14
6	-11	-10	-14	-12	-7	-11	-7	-4	3	8	11
7	-15	-13	-17	-15	-10	-9	-13	-4	1	6	9
8	-20	-13	-14	-9	-6	1	11	16	10	7	7
9	-21	-7	-2	-1	0	4	14	18	16	8	2
10	-24	1	11	5	4	6	14	18	14	7	0
11	-26	-8	2	5	6	7	12	14	13	8	0
12	-26	-13	-7	-1	2	5	10	14	16	11	-1
13	-33	-21	-15	-7	-3	0	6	10	13	6	-7
14	-37	-27	-22	-13	-8	-6	1	6	6	0	-10
15	-39	-32	-26	-18	-13	-10	-4	1	-1	-5	-10
16	-39	-34	-32	-24	-18	-13	-9	-4	-5	-8	-10
17	-44	-40	-37	-29	-23	-19	-11	-8	-8	-9	-9
18	-53	-44	-40	-32	-27	-22	-14	-9	-10	-9	-7
19	-51	-46	-43	-34	-29	-24	-15	-10	-11	-8	-6
20	-55	-49	-44	-36	-29	-25	-15	-10	-9	-8	-6
21	-55	-49	-46	-37	-30	-25	-14	-9	-8	-6	-3
22	-55	-51	-48	-39	-30	-25	-14	-8	-7	-4	-3
23	-61	-55	-49	-40	-30	-25	-15	-7	-5	-3	-2
24	-64	-57	-52	-42	-31	-25	-16	-8	-6	-3	1
25	-64	-57	-52	-42	-33	-27	-18	-11	-9	-4	0
26	-58	-58	-50	-50	-32	-27	-19	-15	-12	-8	-5
27	-52	-48	-46	-26	-28	-25	-22	-18	-15	-10	-6
28	-47	-42	-42	-36	-25	-26	-22	-19	-16	-10	-6
29	-37	-34	-39	-35	-27	-30	-25	-20	-16	-9	-5
30	-29	-28	-33	-31	-26	-25	-25	-17	-12	-7	-2
31	-22	-21	-27	-25	-21	-19	-13	-11	-9	-7	-1
32	-16	-14	-20	-19	-19	-18	-11	-6	-4	-3	-1
33	-9	-9	-13	-12	-14	-13	-8	-1	1	1	0
34	-3	-1	-4	-5	-6	-18	-2	6	7	8	6
34	0	7	7	6	1	-2	3	13	14	14	6

1. Readings in thousandth of an inch
2. Station ½ inch spaced

TABLE I (continued)
DATA SHEET
INITIAL DEFLECTION READINGS
PLATE OF 1/8" NOMINAL DEFLECTION

Station	1	2	3	4	5	6	7	8	9	10	11
0	0	-6	-9	-15	-17	-13	-7	-3	-1	-2	0
1	5	5	14	12	15	15	17	22	19	8	4
2	8	21	47	59	52	49	57	66	60	34	9
3	13	37	64	76	79	80	89	67	85	58	18
4	17	56	78	91	102	104	104	99	92	53	15
5	17	63	89	95	100	99	98	95	80	44	11
6	15	58	86	93	97	98	99	93	83	48	10
7	7	27	76	87	93	97	100	95	95	62	10
8	8	40	69	83	93	91	97	98	89	54	9
9	9	35	66	79	85	89	98	100	95	50	5
10	10	35	62	78	83	83	94	98	99	49	6
11	11	36	72	83	93	89	93	96	87	50	6
12	12	41	74	88	93	86	92	94	81	50	9
13	10	36	70	87	88	79	87	85	73	33	[illegible]
14	7	34	68	85	84	78	85	83	69	30	-2
15	5	35	73	83	87	82	92	90	73	33	-4
16	-3	35	64	76	85	86	99	92	76	31	-8
17	-11	26	58	73	78	84	95	90	76	31	-13
18	-17	22	54	73	82	85	90	87	86	35	-14
19	-26	18	51	72	83	83	86	83	78	38	-14
20	-23	20	62	76	78	85	82	79	77	41	-13
21	-22	24	54	68	76	78	74	70	73	40	-12
22	-16	25	57	74	78	79	80	78	75	35	-11
23	-17	20	52	68	77	82	84	78	69	27	-13
24	-16	15	47	69	77	78	83	77	67	21	-13
25	-16	14	48	66	73	71	81	76	66	22	-13
26	-15	20	51	66	73	72	77	76	66	23	-12
27	-12	29	58	72	76	82	80	79	73	29	-6
28	-10	35	67	76	74	74	79	81	82	35	-2
29	-6	41	64	76	80	85	84	87	84	36	-1
30	-3	37	68	80	79	86	83	93	81	36	2
31	-1	46	73	88	83	87	89	94	80	44	11
32	4	53	64	78	75	77	80	77	75	50	20
33	2	30	43	50	51	54	60	56	57	37	16
34	-1	9	39	23	22	26	31	34	36	26	18
35	-2	-3	2	0	-10	-8	6	24	31	26	25
36	0	-6	-4	-4	-5	-4	0	7	9	10	14

TABLE I (continued)
DATA SHEET
INITIAL DEFLECTION READINGS
PLATE OF 3/16" NOMINAL DEFLECTION

Station	1	2	3	4	5	6	7	8	9	10	11
0	0	1	-3	-6	-8	-8	-7	-6	-4	-4	0
1	2	24	34	26	24	28	22	20	18	6	-3
2	10	48	80	81	81	80	79	69	56	30	4
3	8	53	89	111	118	120	127	107	88	43	2
4	6	55	98	121	136	134	136	120	101	49	-3
5	4	56	97	125	138	144	143	128	109	48	-11
6	4	57	95	119	127	137	135	126	112	47	-12
7	8	62	100	118	126	131	128	120	97	31	-32
8	10	64	102	123	128	135	135	116	78	16	-38
9	11	61	101	124	133	142	140	113	76	11	-44
10	12	60	102	125	134	140	133	115	81	12	-46
11	17	62	102	124	137	139	132	117	80	15	-46
12	21	70	108	122	139	141	134	115	76	8	-50
13	25	87	127	141	150	147	136	116	83	10	-51
14	32	108	139	146	150	145	135	113	82	15	-56
15	33	103	138	140	147	143	135	109	82	15	-59
16	31	111	135	135	143	145	136	114	83	7	-64
17	33	105	130	135	141	143	140	112	82	7	-66
18	33	104	127	135	140	139	136	110	79	7	-66
19	31	101	127	136	139	137	127	154	71	1	-66
20	30	91	124	131	134	132	118	93	64	-7	-65
21	29	88	120	127	131	127	115	88	51	-11	-66
22	28	81	112	124	130	131	119	87	51	-9	-65
23	27	75	109	124	133	138	123	96	61	6	-58
24	27	72	109	119	129	133	124	106	66	6	-56
25	25	66	96	126	130	127	127	99	57	2	-50
26	24	62	94	113	123	127	126	99	52	-6	-52
27	25	64	99	118	125	124	118	98	52	-10	-53
28	26	65	98	113	125	122	111	86	51	-10	-50
29	26	62	90	110	121	117	103	79	47	-8	-46
30	26	58	84	105	113	109	97	78	50	-1	-41
31	25	54	78	92	97	99	93	76	60	9	-32
32	23	46	66	78	85	89	81	64	52	15	-25
33	20	36	55	67	68	69	54	44	38	6	-20
34	13	22	37	45	42	39	27	14	13	-5	-19
35	7	7	6	3	0	1	-6	-11	-10	-15	-18
36	0	-4	-7	-13	-16	-17	-20	-24	-19	-21	-18

TABLE I (continued)
DATA SHEET
INITIAL DEFLECTION READINGS
PLATE OF 1/4" NOMINAL DEFLECTION

Station		1	2	3	4	5	6	7	8	9	10	11	12
0	0	2	0	-2	-5	-6	-9	-11	-7	-7	-7	-4	0
1	0	1	7	13	11	7	4	2	1	4	2	3	-1
2	-1	5	20	36	40	47	38	31	22	14	6	4	-3
3	-6	4	31	58	78	77	68	62	44	25	12	3	-6
4	-14	1	31	77	107	111	111	91	63	37	17	-1	-15
5	-21	-4	48	98	117	124	131	105	74	48	22	-5	-21
6	-27	-10	57	104	119	128	138	115	83	57	28	-12	-30
7	-27	-15	53	100	116	137	136	137	81	50	20	-18	-38
8	-27	-16	43	100	123	144	140	119	84	50	16	-24	-45
9	-25	-19	39	95	127	146	141	127	100	52	19	-28	-48
10	-26	-17	35	93	131	147	146	136	115	77	24	-32	-59
11	-24	-13	39	99	138	153	164	155	126	89	30	-33	-58
12	-27	-14	45	106	142	156	176	168	136	95	35	-36	-62
13	-26	-11	62	117	147	165	183	180	146	104	48	-36	-67
14	-25	-3	81	126	151	171	189	189	153	107	52	-27	-71
15	-26	-5	74	141	151	172	193	194	152	104	43	-39	-72
16	-29	-4	74	129	153	169	190	188	149	103	46	-40	-71
17	-32	-1	87	130	160	175	188	187	147	106	44	-36	-68
18	-33	-2	78	127	160	178	194	187	152	108	46	-31	-63
19	-34	-3	68	116	145	175	200	190	155	116	52	-27	-57
20	-30	-1	65	122	153	179	205	199	161	111	59	-17	-49
21	-25	0	67	126	161	179	207	202	171	121	69	-7	-40
22	-19	1	72	130	162	186	208	203	174	124	67	-2	-32
23	-21	-1	66	122	155	180	207	201	168	123	67	0	-25
24	-23	-2	61	117	155	183	208	201	165	121	65	3	-19
25	-25	-3	61	118	157	190	209	201	165	117	63	3	-17
26	-26	-5	55	113	151	188	207	198	164	112	60	4	-16
27	-28	-9	51	110	149	186	199	193	164	110	60	6	-14
28	-31	-9	44	99	150	189	201	195	165	111	61	9	-13
29	-31	-6	44	97	144	186	203	198	170	115	66	13	-6
30	-28	-4	46	98	137	181	200	198	173	124	72	21	-2
31	-22	0	46	92	130	172	192	195	178	128	80	28	6
32	-15	4	46	87	117	153	176	186	174	126	64	32	13
33	-8	6	39	69	89	116	152	161	158	117	72	31	17
34	-2	8	27	40	56	70	92	102	96	80	49	27	21
35	0	7	15	18	23	26	24	29	33	26	24	21	22
36	0	6	1	-2	9	4	5	7	12	9	14	17	19

TABLE II

Location of Strain Gages

Plate (nominal deflection)		0	1/8"	3/16"	1/4"
Gage Number		Distance from left edge (in)			
1		12.4	0.4	0.4	0.4
2		1.4	1.4	1.4	1.4
3		2.3	2.3	2.3	2.3
4	18	3.75	3.75	3.75	3.75
5	19	5.1	5.1	5.1	5.1
6	20	6.5	6.4	6.4	6.4
7	21	8.0	8.0	8.0	8.0
8	22	10.0	10.0	10.0	10.0
9	23	12.0	12.0	12.0	11.5
10	24	14.0	14.0	14.0	14.0
11	25	16.0	16.0	16.0	16.0
12	26	17.0	17.35	17.6	17.6
13	27	18.75	18.75	18.9	18.9
14	28	20.2	20.1	20.15	20.15
15		21.6	21.6	21.6	21.6
16		22.7	22.5	22.5	22.5
17		23.5	23.5	23.5	23.5
		Distance from outer edge			
A	D	0.5	0.5	0.5	0.5
B	C	1.7	1.7	1.7	1.7
E	H	0.5	0.5	0.5	0.5
F	G	1.7	1.7	1.7	1.7

TABLE III
DATA SHEET
STRAIN LOAD READINGS
PLATE OF ZERO NOMINAL DEFLECTION
FRONT FACE

LOAD IN POUNDS

GAGE NUMBER	0	15000	30000	45000	60000	75000	90000	105000
1	10-1915	12-195	12-425	12-625	12-850	12-1050	12-1260	12-1410
2*	8-1045	8-1260	8-1500	8-1675	8-1880	10-65	10-240	10-335
3	14-0030	14-240	14-425	14-580	14-760	14-930	14-1090	14-1230
4*	8-1225	8-1400	8-1570	8-1715	8-1880	10-30	10-180	10-335
5	14-0010	14-175	14-320	14-460	14-630	14-775	14-925	14-1050
6	8-1170	8-1320	8-1475	8-1615	8-1780	8-1930	10-90	10-240
7	8-1465	8-1600	8-1755	8-1900	10-70	10-220	10-370	10-480
8	10-175	10-310	10-460	10-620	10-800	10-965	10-1125	10-1200
9	14-1075	14-1200	14-1350	14-1510	14-1700	14-1870	16-40	16-180
10	14-920	14-1030	14-1170	14-1320	14-1500	14-1660	14-1820	14-1990
11	14-1170	14-1285	14-1420	14-1545	14-1710	14-1870	16-15	16-180
12	12-1820	12-1925	14-45	14-160	14-310	14-440	14-580	14-810
13	14-50	14-165	14-290	14-400	14-530	14-660	14-790	14-935
14	12-1480	12-1620	12-1760	12-1885	14-20	14-160	14-300	14-430
15	14-445	14-605	14-765	14-905	14-1070	14-1220	14-1370	14-1530
16	12-1480	12-1670	12-1860	14-30	14-225	14-400	14-580	14-750
17	12-1090	12-1310	12-1530	12-1710	12-1935	14-130	14-330	14-530
18	10-610	10-780	10-950	10-1080	10-1245	10-1400	10-1550	12-80
19	10-265	10-435	10-590	10-730	10-900	10-1040	10-1190	10-1430
20	8-1160	8-1315	8-1460	8-1600	8-1760	8-1910	10-65	10-215
21	10-225	10-380	10-530	10-675	10-850	10-1015	10-1180	10-1345
22	10-435	10-540	10-665	10-790	10-940	10-1080	10-1230	10-1355
23	8-1910	10-20	10-130	10-255	10-405	10-540	10-690	10-820
24	10-10	10-115	10-230	10-350	10-500	10-640	10-790	10-940
25	10-1155	10-1260	10-1380	10-1480	10-1630	10-1760	10-1910	12-110
26	8-1330	8-1440	8-1575	8-1700	8-1850	10-005	10-150	10-265
27	8-1185	8-1320	8-1460	8-1590	8-1755	8-1900	10-55	10-1170
28	10-670	10-820	10-965	10-1090	10-1240	10-1390	10-1540	12-260

Strain readings in micro inch per inch

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of Zero Nominal Deflection

Back Face

LOAD IN POUNDS

GAGE NUMBER	0	15000	30000	45000	60000	75000	90000	105000
1	8-870	8-950	8-1035	8-1090	8-1180	8-1280	8-1360	8-1370
2	10-1265	10-1385	10-1505	10-1590	10-1710	10-1815	10-1930	10-1970
3	10-1630	10-1800	10-1945	12-70	12-220	12-350	12-485	12-620
A	10-1870	10-1980	12-90	12-165	12-260	12-335	12-420	12-580
B	10-450	10-430	10-415	10-390	10-380	10-355	10-325	10-280
C	12-000	10-1980	10-1965	10-1935	10-1920	10-1885	10-1855	10-1815
D	10-1800	10-1905	12-0000	12-75	12-170	12-245	12-330	12-490
4	12-340	12-510	12-680	12-825	12-985	12-1130	12-1285	12-1415
5	10-1130	10-1310	10-1480	10-1630	10-1845	10-1950	12-105	12-230
6	10-1800	10-1980	12-170	12-340	12-530	12-705	12-875	12-1090
7	10-835	10-975	10-1130	10-1280	10-1445	10-1600	10-1760	10-1930
8	12-420	12-525	12-670	12-810	12-970	12-1120	12-1270	12-1445
9	8-1410	8-1525	8-1650	8-1790	8-1940	10-100	10-245	10-380
10	10-1650	10-1760	10-1890	12-30	12-195	12-345	12-490	12-670
11	10-1770	10-1900	12-40	12-185	12-340	12-500	12-655	12-825
12	10-1710	10-1850	12-15	12-170	12-340	12-500	12-665	12-930
13	10-1765	10-1930	12-90	12-250	12-415	12-570	12-735	12-890
14	12-180	12-330	12-470	12-610	12-745	12-880	12-1020	12-1145
E	10-540	10-630	10-690	10-750	10-820	10-880	10-940	10-1030
F	10-1475	10-1475	10-1440	10-1415	10-1390	10-1360	10-1320	10-1280
G	10-1460	10-1470	10-1455	10-1420	10-1415	10-1400	10-1370	10-1335
H	12-100	12-200	12-280	12-340	12-425	12-490	12-565	12-650
15	10-1390	10-1530	10-1650	10-1765	10-1890	12-10	12-145	12-280
16	12-465	12-505	12-520	12-550	12-595	12-630	12-680	12-740
17	10-1315	10-1410	10-1490	10-1570	10-1655	10-1750	10-1845	10-1940
18	12-010	12-200	12-360	12-515	12-670	12-820	12-980	12-1640
19	10-1305	10-1490	10-1660	10-1800	10-1965	12-115	12-270	12-560
20	10-1460	10-1630	10-1790	10-1950	12-110	12-260	12-415	12-545
21	12-370	12-520	12-660	12-810	12-970	12-1110	12-1260	12-1375
22	10-1730	10-1890	12-55	12-225	12-410	12-575	12-750	12-880
23	10-1140	10-1285	10-1430	10-1590	10-1770	10-1935	12-110	12-240
24	10-1400	10-1550	10-1690	10-1850	12-30	12-190	12-370	12-545
25	10-530	10-670	10-815	10-965	10-1125	10-1300	10-1465	10-1735
26	10-1980	12-120	12-250	12-390	12-535	12-690	12-840	12-1010
27	10-1710	10-1835	10-1950	12-90	12-220	12-355	12-495	12-1395
28	12-270	12-405	12-520	12-650	12-785	12-915	12-1050	12-1785

Strain readings in micro-inch per inch

TABLE III(continued)

DATA SHEET

Strain -Load Readings

Plate of 1/8" Nominal Deflection

Front Face

LOAD IN POUNDS

GAGE NUMBER	0	20000	35000	50000	65000	80000	95000
1	12-1930	14-600	14-815	14-1000	14-1190	14-1350	14-1530
2	12-1870	14-525	14-750	14-940	14-1130	14-1290	14-1470
3	14-585	14-1175	14-1380	14-1565	14-1755	14-1930	16-100
4	12-980	12-1560	12-1765	12-1940	14-130	14-300	14-450
5	14-1230	14-1865	16-90	16-295	16-450	16-700	16-865
6	14-105	14-790	14-1050	14-1280	14-1530	14-1770	14-1980
7	14-830	14-1525	14-1800	16-50	16-310	16-545	16-760
8	12-640	12-1310	12-1570	12-1810	14-70	14-300	14-510
9	14-590	14-1190	14-1450	14-1680	14-1940	16-180	16-400
10	12-810	12-1415	12-1690	12-1940	14-210	14-455	14-685
11	14-630	14-1240	14-1510	14-1750	16-10	16-240	16-510
12	14-415	14-995	14-1260	14-1485	14-1730	14-1940	16-175
13	12-720	12-1215	12-1415	12-1595	12-1790	12-1965	14-140
14	12-1930	14-420	14-615	14-780	14-955	14-1120	14-1275
15	12-1740	14-210	14-415	14-580	14-765	14-920	14-1080
16	12-80	12-570	12-780	12-960	12-1150	12-1310	12-1490
17	12-540	12-990	12-1220	12-1390	12-1580	12-1750	12-1945
18	12-1610	14-80	14-300	14-485	14-680	14-850	14-1015
19	12-665	12-1060	12-1255	12-1415	12-1600	12-1770	12-1945
20	12-1060	12-1420	12-1605	12-1790	12-1980	14-170	14-370
21	12-760	12-1115	12-1300	12-1475	12-1660	12-1850	14-70
22	12-1875	14-260	14-445	14-620	14-810	14-1000	14-1210
23	12-510	12-980	12-1150	12-1345	12-1550	12-1760	14-10
24	12-1840	14-280	14-480	14-680	14-890	14-1100	14-1355
25	14-1350	14-1755	14-1925	16-100	16-290	16-475	16-670
26	12-1900	14-340	14-505	14-670	14-850	14-1030	14-1210
27	14-1040	14-1470	14-1675	14-1865	16-60	16-240	16-440
28	12-1080	12-1510	12-1715	12-1890	14-80	14-250	14-430

Strain readings in micro-inch per inch

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 1/8" Nominal Deflection

Back Face

LOAD IN POUNDS

GAGE NUMBER	0	2000	35000	50000	65000	80000	95000
1	14-900	14-1210	14-1375	14-1525	14-1680	14-1820	14-1975
2	14-530	14-875	14-1060	14-1220	14-1380	14-1535	14-1700
3	14-610	14-975	14-1170	14-1340	14-1510	14-1665	14-1840
A	14-1800	16-60	16-165	16-265	16-360	16-440	16-515
B	14-720	14-830	14-815	14-800	14-790	14-760	14-710
C	16-20	16-170	16-170	16-165	16-170	16-160	16-120
D	14-980	14-1240	14-1350	14-1450	14-1550	14-1650	14-1730
4	14-1310	14-1660	14-1850	16-25	16-205	16-370	16-540
5	14-970	14-1190	14-1280	14-1370	14-1490	14-1590	14-1690
6	16-360	16-510	16-560	16-610	16-690	16-780	16-870
7	14-1680	14-1805	14-1850	14-1910	16-0	16-105	16-210
8	16-1110	16-1220	16-1260	16-1320	16-1405	16-1510	16-1630
9	16-500	16-580	16-590	16-610	16-680	16-760	16-860
10	14-1045	14-1110	14-1115	14-1140	14-1200	14-1275	14-1350
11	14-1920	16-50	16-80	16-135	16-215	16-300	16-410
12	14-620	14-780	14-830	14-890	14-980	14-1070	14-1170
13	14-1810	16-50	16-155	16-255	16-370	16-480	16-590
14	16-135	16-490	16-670	16-820	16-980	16-1125	16-1270
E	14-1900	16-170	16-280	16-370	16-475	16-560	16-630
F	14-1730	14-1850	14-1870	14-1875	14-1885	14-1890	14-1850
G	14-1530	14-1635	14-1640	14-1640	14-1640	14-1630	14-1510
H	14-505	14-755	14-855	14-950	14-1041	14-1120	14-1190
15	14-890	14-1230	14-1410	14-1575	14-1740	14-1890	16-50
16	14-1190	14-1530	14-1705	14-1850	16-10	16-150	16-300
17	14-1870	16-175	16-320	16-450	16-585	16-700	16-840
18	14-1480	14-1800	14-1965	16-115	16-265	16-400	16-550
19	12-1690	12-1890	12-1970	14-60	14-140	14-225	14-285
20	14-1390	14-1610	14-1705	14-1790	14-1830	14-1970	16-35
21	--	--	--	--	--	--	--
22	14-785	14-1030	14-1130	14-1235	14-1355	14-1470	14-1585
23	14-1130	14-1315	14-1395	14-1470	14-1560	14-1650	14-1730
24	16-145	16-315	16-410	16-480	16-560	16-645	16-715
25	14-1590	14-1840	14-1980	16-100	16-230	16-360	16-475
26	14-1140	14-1380	14-1490	14-1585	14-1685	14-1785	14-1875
27	14-1950	16-175	16-280	16-365	16-455	16-540	16-630
28	14-110	14-1400	14-1590	14-1745	14-1900	16-40	16-200

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 3/16" Nominal Deflection

Front Face

LOAD IN POUNDS

GAGE NUMBER	0	15000	30000	45000	60000	75000	90000	105000
1	8-1430	8-1820	8-1950	10-170	10-350	10-500	10-645	10-880
2	8-170	8-580	8-715	8-960	8-1150	8-1300	8-1465	8-1500
3	8-570	8-1000	8-1155	8-1400	8-1600	8-1775	8-1955	8-1975
4	6-1185	6-1640	6-1815	8-80	8-300	8-485	8-560	8-1945
5	6-1685	8-175	8-380	8-670	8-915	8-1125	8-1370	8-1420
6	8-335	8-900	8-1200	8-1570	8-1890	10-180	10-470	10-335
7	8-540	8-1140	8-1460	8-1850	10-200	10-510	10-755	10-720
8	8-260	8-840	8-1130	8-1490	8-1795	10-85	10-290	10-220
9	8-140	8-730	8-1025	8-1370	8-1670	8-1950	10-110	10-70
10	6-1980	8-645	8-990	8-1385	8-1720	10-50	10-205	10-650
11	6-860	6-1485	6-1820	8-185	8-505	8-800	8-1025	8-840
12	8-120	8-745	8-1050	8-1405	8-1700	8-1995	10-270	10-70
13	8-265	8-835	8-1095	8-1400	8-1655	8-1900	10-150	10-550
14	6-1200	6-1690	6-1895	8-145	8-370	8-560	8-770	10-310
15	8-720	8-1175	8-1355	8-1570	8-1760	8-1940	10-115	10-900
16	8-970	8-1425	8-1600	8-1810	8-1990	10-150	10-340	10-660
17	8-100	8-520	8-690	8-880	8-1050	8-1190	8-1415	8-1530
18	8-190	8-600	8-805	8-1055	8-1260	8-1470	8-1700	10-1100
19	6-1520	6-1880	8-20	8-215	8-370	8-540	8-760	10-1380
20	8-1600	8-1870	8-1905	10-000	10-100	10-200	10-320	10-470
21	6-1690	6-1955	6-1980	8-70	8-160	8-260	8-380	8-565
22	8-1035	8-1330	8-1380	8-1510	8-1625	8-1770	8-960	10-380
23	8-540	8-820	8-885	8-1000	8-1110	8-1250	8-1415	8-1960
24	8-1050	8-1335	8-1390	8-1515	8-1640	8-1780	8-1930	10-420
25	8-1240	8-1490	8-1510	8-1585	8-1675	8-1750	8-1930	10-220
26	8-1180	8-1510	8-1590	8-1735	8-1860	8-1980	10-260	10-310
27	8-1100	8-1535	8-1730	8-1950	10-140	10-330	10-370	10-1385
28	8-920	8-1365	8-1565	8-1795	8-1980	10-165	10-330	10-500

Strain readings in micro-inch per inch.

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 3/16" Nominal Deflection

Back Face

LOAD IN POUNDS

GAGE NUMBER	0	15000	30000	45000	60000	75000	90000	105000
1	8-480	8-855	8-1040	8-1265	8-1450	8-1630	8-1800	10-30
2	10-1425	10-1810	10-1985	12-225	12-410	12-600	12-770	12-800
3	8-1545	8-1915	10-100	10-310	10-495	10-670	10-855	10-920
A	12-445	12-730	12-820	12-930	12-1020	12-1110	12-1180	12-1660
B	12-085	12-270	12-225	12-200	12-160	12-140	12-70	10-1900
C	10-1370	10-1585	10-1570	10-1570	10-1570	10-1550	10-1525	10-1430
D	10-1735	12-45	12-140	12-290	12-400	12-505	12-625	12-1115
4	10-1910	12-180	12-450	12-650	12-825	12-995	12-1190	12-425
5	8-720	8-950	8-985	8-1025	8-1090	8-1140	8-1240	8-1760
6	8-860	8-1010	8-975	8-945	8-950	8-970	8-995	8-1550
7	8-1240	8-1320	8-1230	8-1160	8-1120	8-1090	8-1140	8-1685
8	8-380	8-450	8-350	8-290	8-255	8-270	8-300	8-650
9	6-1750	6-1820	6-1760	6-1710	6-1680	6-1705	6-1760	8-130
10	8-1080	8-1200	8-1130	8-1100	8-1080	8-1110	8-1220	8-1900
11	8-560	8-670	8-590	8-535	8-520	8-540	8-590	8-1210
12	8-490	8-620	8-600	8-595	8-600	8-640	8-710	8-1365
13	8-100	8-350	8-420	8-495	8-570	8-660	8-755	8-1520
14	8-750	8-1140	8-1330	8-1510	8-1660	8-1830	10-240	10-1230
E	10-1935	12-270	12-400	12-525	12-615	12-700	12-850	12-1365
F	10-875	10-1075	10-1070	10-1080	10-1075	10-1040	10-1015	10-945
G	12-175	12-345	12-300	12-260	12-230	12-175	12-105	10-1965
H	12-115	12-430	12-530	12-615	12-695	12-780	12-875	12-1370
15	8-1440	8-1865	10-70	10-260	10-425	10-590	10-790	10-1490
16	6-1505	6-1920	8-120	8-310	8-470	8-635	8-810	8-1115
17	8-985	8-1400	8-1635	8-1815	8-1955	10-120	10-300	10-500
18	12-175	12-520	12-700	12-860	12-1010	12-1190	12-1325	14-740
19	10-1250	10-1515	10-1590	10-1670	10-1750	10-1820	10-1870	10-1580
20	12-085	12-410	12-540	12-690	12-830	12-955	12-1060	12-1345
21	12-800	12-1175	12-1350	12-1540	12-1730	12-1900	14-25	14-255
22	12-275	12-600	12-715	12-890	12-990	12-1115	12-1150	12-1390
23	10-960	10-1295	10-1395	10-1550	10-1685	10-1800	10-1845	10-1965
24	12-650	12-1025	12-1200	12-1375	12-1560	12-1720	12-1825	14-215
25	12-000	12-420	12-620	12-840	12-1050	12-1250	12-1350	12-1650
26	10-1425	10-1785	10-1955	12-130	12-310	12-435	12-460	12-655
27	12-310	12-640	12-760	12-885	12-1020	12-1105	12-1125	12-1030
28	8-375	8-740	8-900	8-1060	8-1205	8-1325	8-1430	8-1545

Strain readings in micro-inch per inch.

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 1/4" Nominal Deflection

Front Face

LOAD IN POUNDS

GAGE NUMBER	0#	10K#	20K#	30K#	40K#	50K#
1	14-445	14-560	14-670	14-760	14-860	14-955
2	14-1080	14-1210	14-1330	14-1450	14-1565	14-1680
3	16-370	16-510	16-640	16-760	16-880	16-1000
4	16-290	16-450	16-605	16-750	16-890	16-1025
5	16-160	16-380	16-590	16-790	16-980	16-1165
6	14-1795	16-95	16-395	16-640	16-890	16-1125
7	14-660	14-950	14-1230	14-1480	14-1720	14-1950
8	14-1290	14-1555	14-1815	16-55	16-280	16-510
9	14-1620	14-1915	16-210	16-470	16-720	16-970
10	14-1050	14-1330	14-1610	14-1875	16-120	16-365
11	14-1525	14-1810	16-100	16-370	16-620	16-875
12	14-590	14-850	14-1110	14-1360	14-1590	14-1820
13	14-1075	14-1285	14-1500	14-1710	14-1895	16-90
14	14-1975	16-140	16-310	16-475	16-625	16-770
15	16-0	16-140	16-280	16-415	16-540	16-665
16	14-1890	16-10	16-130	16-255	16-370	16-485
17	14-890	14-990	14-1100	14-1210	14-1310	14-1410
18	16-60	16-215	16-360	16-500	16-620	16-745
19	16-430	16-560	16-690	16-820	16-930	16-1045
20	14-1280	14-1360	14-1435	14-1510	14-1585	14-1660
21	14-270	14-305	14-340	14-380	14-425	14-470
22	14-1775	14-1810	14-1850	14-1900	14-1940	14-2000
23	14-1475	14-1500	14-1520	14-1560	14-1595	14-1640
24	14-785	14-795	14-805	14-820	14-840	14-870
25	14-1520	14-1505	14-1495	14-1490	14-1490	14-1500
26	14-1205	14-1260	14-1310	14-1365	14-1415	14-1465
27	14-1415	14-1530	14-1640	14-1750	14-1850	14-1940
28	14-1475	14-1605	14-1740	14-1870	14-1985	16-95

Strain readings in micro inch per inch

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 1/4" Nominal Deflection

Front Face (continued)

LOAD IN POUNDS

GAGE NUMBER	60 K#	70 K#	80 K#	90 K#	100 K#	110 K#
1	14-1050	14-1140	14-1230	14-1325	14-1455	14-1645
2	14-1785	14-1890	14-1990	16-100	16-155	16-110
3	16-1110	16-1220	16-1325	16-1430	16-1500	18-280
4	16-1155	16-1280	16-1405	16-1520	18-30	18-1130
5	16-1345	16-1510	16-1680	16-1840	16-1990	18-345
6	16-1360	16-1575	16-1780	16-1990	18-440	18-1260
7	16-190	16-400	16-610	16-825	k6-1215	16-1240
8	16-730	16-940	16-1150	16-1375	16-1485	16-1365
9	16-1215	16-1440	16-1665	16-1915	18-45	18-20
10	16-610	16-830	16-1060	16-1340	16-1445	16-1535
11	16-1130	16-1360	16-1610	16-1930	16-1920	16-1770
12	16-55	16-270	16-490	16-760	16-760	16-920
13	16-280	16-450	16-630	16-820	16-1775	18-1510
14	16-920	16-1055	16-1190	16-1340	18-560	20-30
15	16-790	16-910	16-1025	16-1150	16-1200	16-1300
16	16-600	16-705	16-815	16-925	16-880	16-845
17	14-1510	14-1615	14-1710	14-1810	14-1770	14-1755
18	16-870	16-990	16-1105	16-1220	16-1485	18-800
19	16-1160	16-1270	16-1380	16-1495	16-1880	18-1000
20	14-1730	14-1820	14-1905	16-0	16-345	16-1535
21	14-525	14-590	14-660	14-730	14-905	14-920
22	16-65	16-140	16-225	16-310	16-480	16-1075
23	14-1700	14-1760	14-1840	14-1920	16-125	16-345
24	14-910	14-960	14-1020	14-1090	14-1235	14-1360
25	14-1510	14-1540	14-1575	14-1610	14-1805	14-1935
26	14-1530	14-1590	14-1660	14-1740	14-1985	16-135
27	16-40	16-135	16-235	16-340	16-1290	18-710
28	16-210	16-315	16-430	16-550	16-1840	18-940

Strain readings in micro inch per inch

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 1/4" Nominal Deflection

Back Face

LOAD IN POUNDS

GAGE NUMBER	0#	10K#	20K#	30K#	40K#	50K#
1B	14-395	14-525	14-655	14-780	14-900	14-1010
2	14-1545	14-1670	14-1790	14-1910	16-25	16-135
3	12-1970	14-100	14-230	14-350	14-470	14-580
A	14-1680	14-1740	14-1800	14-1860	14-1915	14-1970
B	14-1835	14-1785	14-1740	14-1705	14-1665	14-1635
C	14-1025	14-1000	14-980	14-970	14-950	14-940
D	14-1545	14-1615	14-1690	14-1760	14-1825	14-1890
4	14-900	14-1025	14-1155	14-1275	14-1390	14-1505
5	14-1020	14-1020	14-1030	14-1045	14-1060	14-1085
6	14-115	14-10	12-1920	12-1855	12-1800	12-1765
7	14-660	14-550	14-450	14-360	14-300	14-255
8	12-570	12-420	12-280	12-160	12-50	10-1965
9	12-220	12-80	10-1960	10-1850	10-1760	10-1690
10	10-1880	10-1730	10-1590	10-1475	10-1370	10-1280
11	14-740	14-590	14-450	14-330	14-215	14-125
12	14-1725	14-1620	14-1515	14-1420	14-1340	14-1275
13	14-1080	14-1065	14-1050	14-1045	14-1040	14-1040
14	14-845	14-970	14-1100	14-1230	14-1350	14-1470
E	16-125	16-200	16-280	16-360	16-440	16-510
F	14-1440	14-1410	14-1390	14-1370	14-1345	14-1330
G	14-1795	14-1730	14-1670	14-1620	14-1565	14-1525
H	14-1085	14-1135	14-1195	14-1250	14-1305	14-1360
15	14-85	14-215	14-360	14-495	14-630	14-755
16	14-1550	14-1685	14-1835	14-1975	16-115	16-250
17	14-1985	16-120	16-275	16-415	16-550	16-685
18	14-1770	14-1885	16-0	16-110	16-215	16-320
19	14-1335	14-1390	14-1435	14-1485	14-1530	14-1580
20	14-1445	14-1530	14-1610	14-1690	14-1770	14-1850
21	14-1660	14-1770	14-1880	14-1990	16-100	16-210
22	14-1465	14-1545	14-1625	14-1710	14-1790	14-1870
23	14-1315	14-1410	14-1510	14-1605	14-1700	14-1800
24	14-810	14-930	14-1050	14-1170	14-1285	14-1405
25	14-1580	14-1680	14-1790	14-1900	16-10	16-120
26	16-20	16-80	16-150	16-220	16-290	16-360
27	14-1350	14-1410	14-1470	14-1530	14-1585	14-1640
28	14-950	14-1050	14-1155	14-1255	14-1355	14-1455

TABLE III (continued)

DATA SHEET

Strain-Load Readings

Plate of 1/4" Nominal Deflection

Back Face (continued)

LOAD IN POUNDS

GAGE NUMBER	$60^{K\#}$	$70^{K\#}$	$80^{K\#}$	$90^{K\#}$	$100^{K\#}$	$110^{K\#}$
1B	14-1130	14-1235	14-1345	14-1450	14-1600	14-1800
2	16-245	16-345	16-450	16-550	16-540	16-580
3	14-690	14-790	14-900	14-1005	14-1055	14-1710
A	16-30	16-85	16-140	16-195	16-480	16-1160
B	14-1610	14-1580	14-1560	14-1530	14-1450	14-1320
C	14-930	14-920	14-915	4-900	14-840	14-730
D	14-1960	16-20	16-90	16-150	16-435	16-1095
4	14-1620	14-1720	14-1830	14-1940	16-460	16-1410
5	14-1115	14-1145	14-1180	14-1225	14-1330	14-1600
6	12-1740	12-1730	12-1730	12-1740	14-15	14-350
7	14-220	14-205	14-200	14-200	14-390	14-885
8	10-1890	10-1830	10-1790	10-1750	12-30	12-465
9	10-1625	10-1585	10-1550	10-1520	10-1725	12-55
10	10-12[illegible]0	10-1145	10-1100	10-1040	10-1320	10-1770
11	14-40	12-1975	12-1920	12-1850	14-260	14-840
12	14-1220	14-1170	14-1130	14-1090	14-1525	16-90
13	14-1040	14-1050	14-1070	14-1080	14-1470	16-235
14	14-1590	14-1695	14-1810	14-1930	18-15	18-1455
E	16-590	16-655	16-730	16-795	18-130	18-1465
F	14-1310	14-1300	14-1285	14-1260	14-1100	14-1030
G	14-1480	14-1450	14-1410	14-1365	14-1170	14-1070
H	14-1420	14-1470	14-1530	14-1580	16-640	16-1715
15	14-880	14-995	14-1120	14-1235	14-1385	14-1530
16	16-380	16-500	16-620	16-740	16-755	16-795
17	16-815	16-930	16-1055	16-1170	16-1215	16-1260
18	16-420	16-510	16-610	16-705	16-865	16-1830
19	14-1625	14-1670	14-1720	14-1760	14-6785	16-80
20	14-1930	16-10	16-90	16-155	16-240	16-800
21	16-320	16-430	16-540	16-635	16-620	16-925
22	14-1950	16-30	16-105	16-175	16-255	16-410
23	14-1890	14-1990	16-80	16-165	16-185	16-510
24	14-1520	14-1640	14-1760	14-1875	16-255	16-940
25	16-230	16-340	16-455	16-555	16-555	16-985
26	16-430	16-500	16-570	16-640	16-640	16-875
27	14-1690	14-1745	14-1805	14-1860	14-1890	16-590
28	14-1545	14-1640	14-1735	14-1825	16-850	16-1910

APPENDIX B

STRAIN LOAD VALUES

TABLE IV

Strain-Load Values

Gage Number	Plate of Zero Nominal Deflection — Load in Kips 20	40	60	80	100	Plate of 1/8" Nominal Deflection — Load in Kips 20	40	60	80	100
1	285	570	855	1135	1390	250	500	750	1000	1250
1	110	220	325	435	510	200	400	600	800	1000
1	192.5	395	590	785	950	225	450	675	900	1125
2	245	495	740	990	1185	240	480	720	960	1200
2	145	285	430	580	680	210	425	640	850	1065
2	195	390	585	785	932.5	225	452.5	680	905	1132.5
3	220	440	660	880	1095	250	500	755	1005	1260
3	185	370	550	735	920	225	450	670	895	1120
3	202.5	405	605	807.5	1007.5	237.5	475	712.5	950	1190
4	205	410	625	830	1035	250	495	745	990	1240
4	205	410	625	830	1035	235	470	710	945	1180
4	205	410	625	830	1035	242.5	492.5	727.5	967.5	1210
5	200	400	600	800	1000	270	545	815	1090	1360
5	215	425	640	850	1060	140	280	420	560	700
5	207.5	412.5	620	825	1030	205	412.5	617.5	825	1030
6	205	410	610	820	1020	325	655	985	1310	1640
6	240	480	720	960	1200	50	120	205	305	445
6	222.5	445	665	890	1110	187.5	387.5	595	807.5	1042.5
7	200	400	600	800	1000	370	730	1070	1390	1670
7	200	400	610	830	1040	35	95	200	330	480
7	200	400	605	815	1020	202.5	417.5	635	860	1075
8	180	390	620	855	1015	360	700	1035	1345	1630
8	180	365	555	760	980	20	80	175	310	480
8	180	377.5	587.5	807.5	997.5	190	390	605	827.5	1055
9	220	440	660	880	1100	350	690	1020	1335	1635
9	150	330	530	740	930	- 20	- 15	+ 50	+100	+260
9	185	385	595	810	1015	165	337.5	525	747.5	947.5
10	170	370	580	800	1030	375	740	1090	1420	1700
10	150	330	530	740	960	0	10	70	170	270
10	160	350	555	770	995	187.5	375	580	795	985
11	160	340	540	740	950	370	720	1060	1375	1700
11	175	370	580	790	1005	50	70	155	275	420
11	167.5	355	500	765	977.5	210	395	607.5	825	1060
12	150	405	570	760	1000	330	660	970	1270	1560
12	200	505	720	950	1220	30	100	200	320	400
12	195	405	645	855	1110	180	380	585	795	1010

Strains in Micro-Inch Per Inch
F indicates gage on front face
B indicates gage on back face
m indicates mean value

TABLE IV (Cont.)

Gage Number	Plate of Zero Nominal Deflection — Load in Kips 20	40	60	80	100	Plate of 1/8" Nominal Deflection — Load in Kips 20	40	60	80	100
13	155	315	475	650	830	270	530	780	1020	1250
13	220	430	645	860	1080	130	275	415	560	710
13	187.5	372.5	560	755	955	200	402.5	597.5	790	980
14	180	360	540	720	900	245	490	720	945	1150
14	190	380	560	745	920	225	445	660	860	1050
14	185	370	550	732.5	910	235	467.5	690	902.5	1100
15	205	410	620	825	1030	255	510	750	980	1180
15	165	335	500	670	835	230	460	685	900	1100
15	185	372.5	560	747.5	932.5	242.5	485	717.5	940	1140
16	255	500	745	980	1210	295	555	800	1030	1260
16	145	285	430	580	680	230	450	650	850	1050
16	200	392.5	587.5	780	945	262.5	502.5	725	940	1155
17	270	540	810	1080	1360	265	520	775	1020	1265
17	95	200	320	440	565	190	380	560	720	930
17	182.5	370	565	760	962.5	227.5	450	662.5	870	1097
18F	205	410	615	820	1150	240	485	730	970	1210
18B	205	415	625	830	1200	200	405	610	810	1010
18M	205	412.5	620	825	1175	220	445	670	890	1110
19F	200	400	600	805	1050	230	460	690	925	1160
19B	200	400	600	805	1080	110	225	340	450	530
19M	200	400	600	805	1065	170	342.5	505	687.5	845
20F	200	400	600	800	1000	250	500	755	1010	1260
20B	210	420	630	840	1050	115	235	350	470	590
20M	205	410	615	820	1025	182.5	367.5	552.5	740	925
21F	220	440	655	870	1090	240	485	730	970	1220
21B	195	395	595	790	990	170	340	520	690	870
21M	207.5	417.5	625	830	1040	205	412.5	625	830	1045
22F	180	360	545	730	910	245	490	735	980	1230
22B	225	450	680	905	1130	150	310	465	620	780
22M	202.5	405	612.5	817.5	1020	197.5	400	600	800	1005
23F	185	370	550	740	925	260	520	790	1060	1320
23B	220	440	660	880	1105	110	225	340	450	660
23M	202.5	405	605	810	1015	185	372.5	565	755	990
24F	190	390	580	775	870	270	545	820	1090	1570
24B	225	450	675	900	1120	105	220	330	440	520
24M	207.5	420	627.5	837.5	1045	187.5	382.5	575	765	1045
25F	165	335	500	665	900	240	480	725	960	1210
25B	195	390	600	830	1140	170	340	520	690	870
25M	180	362.5	550	747.5	1020	205	410	622.5	825	1040

Strains in Micro-Inch Per inch
F indicates gage on front face
B indicates gage on back face
M indicates mean value

TABLE IV (Cont.)

Gage Number	Plate of Zero Nominal Deflection — Load in Kips 20	40	60	80	100	Plate of 1/8" Nominal Deflection — Load in Kips 20	40	60	80	100
26F	190	380	570	760	955	215	430	660	900	1135
26B	180	370	560	750	940	130	200	390	520	650
26M	185	375	565	755	947.5	172.5	345	525	760	892.5
27F	195	390	585	780	1080	250	510	765	1020	1275
27B	165	335	510	690	1000	115	230	350	570	680
27M	180	362.5	547.5	735	1040	182.5	370	557.5	795	977.5
28F	190	380	575	765	1080	240	490	735	980	1220
28B	165	335	510	685	990	200	400	605	810	1010
28M	180	357.5	542.5	725	1035	220	445	670	895	1115
A	150	275	390	500	620	145	290	420	530	620
D	140	260	375	480	605	150	300	435	560	670
-M	145	267.5	382.5	490	612.5	147.5	295	427.5	545	645
B	-15	-35	-60	-95	-145	-10	-20	-40	-80	-145
C	-25	-55	-90	-125	-170	-00	0	0	-10	- 75
-M	-20	-45	-75	-110	-157.5	- 5	-10	-20	-45	-110
E	80	165	250	335	415	150	285	415	530	620
H	100	200	300	400	500	140	270	395	505	595
-M	90	182.5	275	362.5	457.5	145	277.5	405	517.5	607.5
F	-30	-00	-100	-140	190	+20	+40	+60	+60	0
G	-20	-40	-70	-95	135	+ 5	+10	+10	-10	-60
-M	-25	-50	-85	117.5	162.5	125	25	35	25	-30

Strains in Micro-Inch Per Inch
F indicates gage on front face
B indicates gage on back face
M indicates mean value

TABLE IV (Cont.)

Strain Load Values

Gage Number	Plate of 3/16" Nominal Deflection — Load in Kips 20	40	60	80	100	Plate of 1/4" Nominal Deflection — Load in Kips 20	40	60	80	100
1F	215	435	655	875	1115	225	415	600	785	1010
1B	235	480	720	960	1220	255	500	720	940	1200
1M	225	457.5	687.5	917.5	1167.5	240	457.5	660	862.5	1105
2F	230	450	675	900	1035	240	475	705	915	1065
2B	250	490	735	975	1125	240	475	705	915	1055
2M	240	470	705	932.5	1080	240	475	705	915	1060
3F	250	500	750	1000	1140	250	490	725	935	1110
3B	240	480	720	965	1130	265	510	730	935	1090
3M	245	490	735	982.5	1135	257.5	500	727.5	935	1100
4F	270	540	810	1080	1390	310	600	865	1115	1810
4B	240	470	710	950	1230	250	490	720	930	1500
4M	255	505	760	1015	1310	280	545	792.5	1022.5	1685
5F	305	610	925	1230	1420	410	810	1175	1510	1820
5B	75	150	225	310	600	20	45	95	165	310
5M	190	380	575	770	1010	215	427.5	635	837.5	1065
6F	400	810	1220	1620	1740	600	1100	1580	2000	2700
6B	-70	-115	-110	-90	+100	-200	-320	-380	-390	- 90
6M	165	347.5	555	765	920	200	390	600	805	1305
7F	470	935	1400	1800	1960	560	1070	1540	1970	2570
7B	-140	-245	-315	330	-125	-220	-360	-440	-460	-270
7M	165	345	542.5	735	917.5	170	355	550	755	1150
8F	450	885	1290	1660	1760	520	990	1440	1860	2200
8B	-160	-270	-320	-300	-155	-300	-530	-690	-800	-550
8M	145	307.5	485	680	802.5	110	230	375	530	825
9F	440	860	1260	1640	1710	600	1100	1580	2250	2430
9B	-90	-165	-210	-195	+ 60	-280	-480	-620	-700	-500
9M	175	347.5	525	722.5	885	160	310	480	775	960
10F	620	1120	1560	1980	2390	560	1080	1560	2040	2410
10B	-110	-180	-200	-140	+200	-300	-520	-690	-790	-500
10M	260	470	680	920	1295	130	280	435	625	925
11F	490	950	1380	1760	1830	580	1100	1600	2090	2400
11B	-130	-220	-250	-220	- 10	-280	-530	-700	-810	-480
11M	180	365	565	770	910	150	285	450	640	960
12F	450	990	1300	1690	1660	520	1000	1460	1990	2160
12B	-35	-50	-45	+10	+230	-220	-390	-510	-600	-100
12M	207.5	470	677.5	850	945	150	305	475	695	1030

Strain Micro-Inch Per Inch
F indicates gage on front face
B indicates gage on back face
M indicates mean value

TABLE IV (Cont.)

Strain Load Values

Gage Number	Plate of 3/16" Nominal Deflection — Load in Kips					Plate of 1/4" Nominal Deflection — Load in Kips				
	20	40	60	80	100	20	40	60	80	100
13F	330	660	1000	1330	1700	440	840	1190	1560	2710
13B	85	180	280	400	730	-20	-40	-40	-20	200
13M	207.5	420	640	865	1215	210	400	575	770	1455
14F	275	550	830	1105	1500	350	560	950	1230	2600
14B	265	510	720	990	1300	260	510	740	960	3160
14M	270	530	775	1047.5	1400	305	585	845	1095	2880
15F	290	550	780	1000	1900	285	545	795	1035	1200
15B	260	515	760	1005	1845	285	545	795	1040	1300
15M	275	532.5	770	1002.5	1872.5	285	545	795	1037.5	1250
16F	290	560	790	1010	1310	240	480	710	920	990
16B	275	530	760	970	1265	280	560	830	1075	1210
16M	282.5	545	775	990	1287.5	240	520	770	997.5	1100
17F	235	470	705	940	1160	200	400	600	800	860
17B	235	470	705	940	1180	290	565	830	1070	1230
17M	235	470	705	940	1170	245	482.5	715	935	1045
18F	285	570	855	1140	1450	300	570	815	1050	1405
18B	215	430	650	860	1080	230	445	650	840	1065
18M	250	500	752.5	1000	1265	265	507.5	732.5	945	1235
19F	220	440	665	890	1340	260	505	730	960	1380
19B	100	205	310	405	275	100	195	290	380	450
19M	160	322.5	487.5	647.5	807.5	180	350	510	670	915
20F	185	370	560	740	950	150	305	460	620	960
20B	125	260	385	520	705	160	325	485	650	880
20M	155	315	472.5	630	827.5	155	315	472.5	635	920
21F	120	245	370	495	700	70	150	255	390	630
21B	240	480	720	950	1160	220	440	670	880	960
21M	180	362.5	545	722.5	930	145	295	462.5	635	795
22F	160	320	490	685	1050	80	165	285	445	710
22B	140	300	490	630	800	160	320	480	640	820
22M	150	310	490	657.5	925	120	242.5	382.5	542.5	765
23F	150	295	450	630	1000	40	120	225	365	645
23B	205	410	600	735	830	190	390	580	770	880
23M	177.5	352.5	525	682.5	915	115	255	402.5	567.5	762.5
24F	170	335	505	685	990	250	485	720	960	1450
24B	240	480	720	920	1170	30	65	130	235	450
24M	205	407.5	612.5	802.5	1080	140	275	425	597.5	950
25F	80	175	285	440	690	-20	-25	0	60	290
25B	300	585	860	1095	1330	220	440	660	880	100.0
25M	190	380	572.5	767.5	1010	100	207.5	330	470	645

Strain in Micro Inch Per Inch
F indicates gage on front face
B indicates gage on back face
M indicates mean value

TABLE IV (Cont.)

Strain Load Values

Gage Number	Plate of 3/16" Nominal Deflection — Load in Kips 20	40	60	80	100	Plate of 1/4" Nominal Deflection — Load in Kips 20	40	60	80	100
26F	170	345	515	700	975	160	220	320	450	780
26B	230	460	700	820	970	140	280	420	560	645
26M	200	402.5	607.5	760	972.5	125	250	370	505	717.5
27F	245	500	770	1060	1550	220	430	625	815	1860
27B	170	330	500	600	570	120	235	340	450	540
27M	207.5	415	635	830	1060	170	332.5	482.5	632.5	1200
28F	310	590	850	1080	1310	260	500	730	950	2340
28B	235	450	640	810	950	200	390	590	780	20.00
28M	272.5	520	745	945	1130	230	445	660	865	2170
A	140	275	400	510	730	120	230	350	460	800
D	170	340	490	630	910	140	280	410	540	890
-	155	307.5	445	570	820	130	255	380	500	845
B	-50	-90	-135	-190	-315	-100	-180	-225	-275	-385
C	- 5	- 5	-10	-25	-100	- 55	-75	-100	-115	-190
-	-27.5	-47.5	-72.5	-107.5	-207.5	-77.5	-127.5	-162.5	-195	-287.5
E	170	350	485	600	980	160	320	470	605	2005
H	115	230	340	455	710	110	225	335	445	1540
-	142.5	290	412.5	527.5	845	135	272.5	402.5	525	1772.5
F	+10	+10	+ 5	-25	-90	-55	-95	-130	-160	-340
G	-70	-125	-180	-245	-370	-75	-230	-315	-375	-615
-	-30	-57.5	-85	-135	-230	-65	-162.5	-222.5	-267.5	-477.5

Strain in Micro Inch Per Inch
F indicates gage on front face
B indicates gage on back face
M indicates mean value

APPENDIX C

AVERAGE INITIAL DEFLECTION AND AVERAGE

STRAIN CALCULATIONS

Table V

Calculation of the [illegible] Deflection

Plate of Low Nominal Deflection

Upper Edge	Lower Edge	Center
-6	-47	-26
-5	-5[illegible]	-7
+1	-64	-25
-3	-55	-15
-6	-5[illegible]	[illegible]
-7	-53	[illegible]
[illegible]	-37	-23
[illegible]	-37	-6
-2	-26	+5
3	-24	+6
+7	[illegible]	+1
-40	-478	-157
	- 40	+[illegible]
	-518	+10[illegible]
Average	-259	
		= 0.0093"
		= 0.175'
		= 0.2745

Plate of [illegible] Nominal Deflection

Upper Edge	Lower Edge	Center
[illegible]	-16	74
-12	-2[illegible]	[illegible]
-13	-16	[illegible]
[illegible]	-16	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	-19	[illegible]
-8	-9	[illegible]
[illegible]	+7	[illegible]
+9	+12	[illegible]
+6	+10	[illegible]
[illegible]	+5	[illegible]
-51	-6[illegible]	[illegible]
	-51	[illegible]
	-114	[illegible]
	- 57	
		= [illegible]
		= [illegible]
		= [illegible]

Plate of 3/16" Nominal Deflection

Upper Edge	Lower Edge	Center
10	-33	13[illegible]
12	-46	[illegible]
21	-50	141
32	-56	143
31	-64	149
33	-66	[illegible]
30	-68	13[illegible]
[illegible]	-6[illegible]	13[illegible]
[illegible]7	-5[illegible]	[illegible]
[illegible]4	-5[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
+274	-6[illegible]	+1490
	+274	+ 167
	-331	+1657
Average	-167	
		= [illegible]6"
		= [illegible]"
		= [illegible]

Plate of 1/4" Nominal Deflection

Upper Edge	Center	Lower Edge
-46	240	-37
-59	256	[illegible]
-6[illegible]	270	-47
-7[illegible]	[illegible]	[illegible]
-71	[illegible]	[illegible]
-63	[illegible]	[illegible]
-4[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-4[illegible]
-33	[illegible]	[illegible]
-26	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
-500	+[illegible]7	-[illegible]
	+ [illegible]	[illegible]
	+[illegible]	[illegible]
		-[illegible]
		= [illegible]
		= [illegible]
		= [illegible]

TABLE VI

Calculation of the Mean Strain

	Plate of Zero Nominal Deflection					Plate of 3/16" Nominal Deflection				
Load(Kips)	20	40	60	80	100	20	40	60	80	100
	Strain (Micro-inch Per Inch)					Strain (Micro-inch Per Inch)				
	9.0	20.0	29.5	39.3	47.8	11	22.5	34	45.6	59.9
	9.7	20.0	30.0	40.0	49.0	12.2	24.0	36.2	48.3	55.9
	10.1	20.4	31.2	41.3	51.7	12.0	24.0	36.0	48.2	62.2
	10.2	21.7	32.7	43.3	54.0	8.7	17.8	28.0	38.2	47.2
	10.0	20.0	30.0	41.0	51.0	8.3	17.2	27.0	36.8	46.0
	9.0	18.8	29.4	30.2	49.8	7.4	15.5	24.2	34.0	40.2
	9.5	19.0	29.8	40.5	50.8	8.8	17.3	26.3	36.1	44.0
	8.0	17.5	28.0	38.3	49.6	13.0	23.4	34.0	46.0	64.8
	8.2	18.0	28.0	38.0	48.0	9.1	18.4	28.2	38.5	45.3
	9.0	19.4	30.3	40.3	51.8	10.3	22.6	33.2	42.7	51.5
	9.2	18.5	27.5	36.7	45.6	13.0	25.8	38.0	50.0	70.0
	9.5	19.0	28.5	38.0	46.7	14.0	26.9	38.7	49.8	65.3
	8.8	18.0	28.0	37.7	48.5	10.5	21.6	33.5	45.9	56.1
Sum	120.2	250.3	392.9	504.6	639.3	138.3	277.0	417.3	570.1	708.4
Mean Value	185	384.5	604.8	775	982.5	212.8	426	642	876	1090

	Plate of 1/8" Nominal Deflection					Plate of 1/4" Nominal Deflection				
	Strain (Micro-inch Per Inch)					Strain (Micro-inch Per Inch)				
	11.1	22.3	33.7	45.0	56.0	12.0	22.4	32.2	42.1	56.1
	11.6	23.3	35.0	47.0	58.5	12.5	24.6	36.0	46.4	54.3
	11.8	23.9	35.3	47.0	58.7	13.6	26.3	38.3	49.8	79.1
	9.8	19.8	30.0	40.8	51.9	10.2	20.0	30.6	40.8	61.5
	10.0	21.0	31.8	42.8	53.7	8.4	18.0	27.2	37.7	57.3
	9.5	19.5	30.2	41.5	53.0	5.5	11.6	18.8	26.6	41.1
	8.0	16.8	26.2	37.2	47.3	7.8	15.2	23.7	37.3	47.8
	9.2	18.7	29.0	39.7	49.2	6.7	14.0	21.9	31.3	46.2
	10.5	19.7	30.2	41.2	53.0	7.5	14.3	22.5	32.0	48.0
	9.5	19.5	29.5	39.5	49.5	8.5	17.0	25.4	36.0	58.5
	11.4	23.0	34.0	44.3	54.0	14.7	28.0	40.6	53.0	129.0
	12.4	24.5	36.0	47.0	57.2	13.3	26.7	39.1	41.0	60.8
Sum	135.0	273.0	412.4	554.5	694.8	133.1	261.4	390.5	529.0	788.7
Mean Value	207.7	420	633	851	1069	204.8	402	601	813	1212

TABLE VII

Calculation of the Average Maximum Strain

Front Face

Load (Kips)	Gage Number	NOMINAL DEFLECTION 0	1/8	3/16	1/4
20	7	200	370	470	560
	11	160	370	490	580
	Average	180	370	480	570
	Ratio	0.973	1.782	2.255	2.78
40	7	400	730	935	1070
	11	340	720	950	1100
	Average	370	725	942.5	1085
	Ratio	0.962	1.728	2.215	2.70
60	7	600	1070	1400	1540
	11	540	1060	1380	1000
	Average	570	1065	1390	1570
	Ratio	0.945	1.684	2.165	2.615
80	7	800	1390	1800	1970
	11	740	1375	1760	2090
	Average	770	1382.5	1780	2030
	Ratio	0.933	1.626	2.030	2.498
100	7	1000	1670	1960	2570
	11	950	1700	1830	2400
	Average	975	1685	1925	2485
	Ratio	0.993	1.578	1.766	2.050

TABLE VII (Cont.)

Calculation of the Average Minimum Strain

Back Face

Load (Kips)	Gage Number	NOMINAL DEFLECTION 0"	1/8"	3/16"	1/4"
20	8	180	20	-160	- 300
	9	150	-20	- 90	- 280
	10	150	0	-110	- 300
	Average	160	0	-120	- 293.3
	Ratio	0.865	0	-0.564	-1.430
40	8	365	80	-270	- 530
	9	330	-15	-165	- 480
	10	330	10	-180	- 520
	Average	341.6	25	-205	- 510
	Ratio	0.888	0.059	-0.481	-1.269
60	8	555	175	-320	- 690
	9	530	50	-210	- 620
	10	530	70	-200	- 690
	Average	538.3	98.3	-243.3	- 666.6
	Ratio	0.891	0.155	-0.379	-1.109
80	8	760	310	-300	- 800
	9	740	160	-195	- 700
	10	740	170	-140	- 790
	Average	746.6	213.3	-211.6	- 763.3
	Ratio	0.964	0.250	-0.241	-0.949
100	8	980	480	-155	- 550
	9	930	260	+ 60	- 510
	10	960	270	+300	- 560
	Average	956.6	336.0	+ 35	- 540
	Ratio	0.975	0.315	0.032	-0.445

TABLE VII (Cont.)

Calculation of the Average Maximum Strain

Middle Depth

Load (Kips)	Gage Number	NOMINAL DEFLECTION 0"	1/8"	3/16"	1/4"
20	4	205	242.5	255	280
	14	185	235	270	305
	Average	195	238.7	262.5	292.5
	Ratio	1.055	1.150	1.232	1.429
40	4	410	492.5	505	545
	14	370	467.5	530	585
	Average	390	480.0	517.5	565
	Ratio	1.013	1.143	1.215	1.406
60	4	625	727.5	760	792.5
	14	550	690.0	775	845.0
	Average	587.5	708.7	767.5	818.7
	Ratio	0.972	1.120	1.196	1.361
80	4	830	967.5	1015	1022.5
	14	732.5	902.5	1047.5	1995.0
	Average	781.2	935.0	1031.2	1508.7
	Ratio	1.009	1.100	1.179	1.855
100	4	1035	1210	1310	1685
	14	910	1100	1400	2880
	Average	972.5	1155	1355	2282
	Ratio	0.990	1.081	1.242	1.886

APPENDIX D

mon
MEASURED AND CALCULATED APPLIED LOAD

Nominal Deflection	0	1/8"	3/16"	1/4"
Average Strain in the Plate (micro-in/in)	604.8	642.0	633.3	601.1
Product Strain-Cross Sectional Plate Area	1814.4	1926.0	1899.0	1803.0
Maximum Strain in Stiffeners	700	720	800	750
	520	650	750	820
Minimum Strain in Stiffeners	-260	-200	-270	-375
	-235	-120	-300	-475
Average Strain in the Stiffeners	181.3	262.5	245.0	180.0
Product Strain Cross-Sectional Stiffeners Area	226.6	328.0	306.0	225.0
Sum of Products Strain-Area	2041.0	2254.0	2205.0	2028.0
Calculated Applied Load (pounds)	59200	65400	64000	58900
Measured Load	60000	60000	60000	60000
Difference (pounds)	-800	+5400	+4000	-1100
Difference (percentage)	-1.3%	+9%	+6.7%	-1.8%

APPENDIX E

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The effect of initial deflection on the stress distribution in a panel of plating of a ship under tensile load.

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